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**Wildlife and
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Wildlife and Fisheries Habitat Improvement Handbook







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WILDLIFE AND FISHERIES

HABITAT IMPROVEMENT HANDBOOK

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and

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Technical Editors

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Preface

This handbook replaces FSH 2609, Wildlife and Fish Habitat Improvement Handbook, which was published in 1969. Though it was initially planned as a revision of FSH 2609, this handbook has been completely rewritten and expanded into an administrative report. It is designed to give biologists and other habitat resource managers a comprehensive reference source that covers a wide array of structural and nonstructural habitat improvement practices suited for both wildlife and fish.

Dr. Neil Payne, a professor of wildlife, and Dr. Frederick Copes, a professor of fisheries, at the University of Wisconsin-Stevens Point made a comprehensive review of the literature and wrote the manuscript. A team of Forest Service wildlife and fisheries biologists from Regions and Forests then reviewed the manuscript, and their comments and suggestions were incorporated into the final manuscript.

Specifically, this publication responds to the need for an updated reference of practical methods to carry out wildlife and fish habitat improvement. Any of the techniques described here, when adapted to fit local and regional situations, should help improve management of wildlife and fisheries habitats on National Forest System lands and on other forests and rangelands.

One challenge in writing the handbook was trying to balance competing objectives. While we have tried to maintain proven procedures from the old handbook and add new material, we have also tried to keep the size of the handbook manageable. As a result, this publication does not provide guidelines specific to each Region or Forest and, thus, may lack the indepth treatment that some readers will inevitably want. What we hope is that in these pages every reader will find the tools necessary to at least form a good approach to a specific problem.

Consistent with this last point, we consider these procedures guidelines, not prescriptive direction. Successfully accomplishing wildlife and fisheries habitat improvements, whether structural or nonstructural, requires ingenuity and resourcefulness on the part of the biologist, who must assess the need for habitat improvements, use locally available materials and resources (including volunteers), and adapt appropriate procedures to site-specific applications. These guidelines are also fully in keeping with the Forest Service's emphasis on resources coordination--that is, the

effort to have wildlife and fisheries biologists work in close consultation with other resource specialists to design projects that will successfully enhance wildlife and fisheries habitat. Accordingly, this handbook frequently invites the reader to seek necessary guidance by consulting with other professionals or other sources of local expertise, such as engineers, soil scientists, hydrologists, State fish and wildlife biologists, and state extension specialists. Besides offering an extensive bibliography, this handbook also frequently refers the user to literature sources for detailed descriptions of specific procedures.

Habitat improvement is a dynamic process that is constantly being improved and expanded by new techniques and refinements of the old. For these reasons, we encourage users to keep up with the state of the art through the literature, including the several excellent Regional newsletters that emphasize habitat improvement practices. We also encourage users to become involved, to share their ideas with others so successful practices used in their area may be used and adapted elsewhere.

Robert D. Nelson
Director of Wildlife and Fisheries

Introduction

Three major elements of wildlife habitat are food, water, and cover. The size of individual territories or home ranges for wildlife is determined to some extent by the abundance and interspersion of these three elements. Any cultural or natural development that increases the supply of food, water, and cover or improves their distribution will tend to increase an area's carrying capacity. Any such development that decreases the supply or restricts the distribution of these elements will tend to reduce the carrying capacity of an area.

There are two approaches to wildlife habitat improvement, one direct and the other indirect. The direct approach improves habitat by using tools and mechanical techniques. The indirect approach achieves the same results by manipulating natural forces in the environment--for example, by increasing deer harvest to reduce browsing pressure and to improve habitat conditions.

Because an effective wildlife and fisheries program requires a balance between direct and indirect habitat management, the Forest Service uses both these methods. Direct habitat improvements are especially necessary to meet wildlife and fisheries management objectives. Such methods, which are included in Forest Plans and in cooperative State fish and wildlife management plans, are a major part of the Forest Service wildlife and fisheries program and normally provide the only opportunities to improve habitat for fish, threatened and endangered species, and waterfowl. At the same time, as demands increase for commodity production from National Forest System lands, indirect habitat improvements--improvements resulting from the Forest Service's desire to take wildlife and fisheries needs into account in the management of other resources--are also requiring more input from biologists.

While it may be desirable to use both approaches simultaneously, indirect methods are often less expensive and more effective and can be used over large areas. Also, direct habitat improvement is costly. Therefore, the direct method generally is undertaken only under certain conditions:

(1) When it provides the nucleus for improving a larger area of habitat--that is, when direct improvement of a small area will make a larger habitat area usable or substantially better.

(2) When it is the only way to provide a missing essential habitat factor.

(3) When it is needed to restore habitat that has been damaged or altered by human activity or by catastrophic weather conditions, and that will not be restored naturally within a reasonable time period.

Whatever method is chosen, it is important to consider the ecological implications of that technique. This guide should prove helpful in weighing these decisions and in reviewing a wide array of options and general considerations. This guide primarily discusses direct improvement techniques on stream, lake, upland, and wetland habitats. Both structural and nonstructural techniques are included, some of which must be coordinated with other habitat uses such as timber harvesting. Fish and wildlife habitat improvement methods used throughout the Forest Service are described in these pages. While many of these methods originated within the Forest Service, others have been developed by cooperators, and still others have been taken from the general literature. Most of them have wide application, and nearly all continue to be refined.

This guide is meant to serve as a reservoir of ideas and techniques for resource managers to adapt and modify. It also provides a base from which new procedures and techniques can be developed. And, it can be used as a training vehicle for those who plan and develop habitat improvement projects. Many of the methods discussed in this document have been field and time tested. In most cases, they will produce good results when applied as described. At times, innovations still may be needed, and they are encouraged.

This publication is not intended to provide technical project planning details, nor to establish a fixed set of standard techniques. Information concerning various habitat improvement methods is provided as a guide for project selection and completion. Literature citations refer users to references that provide more details about the techniques discussed.

Chapter 1
Stream Habitat Improvement

STREAM IMPROVEMENT APPLICATIONS

Stream improvement concerned with fish habitat applies to the installation of instream devices or application of streamside procedures for correcting natural damage or problems caused by humans (White and Bryunildson 1967). The primary purpose of stream habitat improvement is to improve cover, increase stream areas suitable for fish habitat, and increase spawning area. Through the installation of structures and modification of conditions within or along the stream, stream habitat improvement also is designed to protect existing habitat from damaging erosion. Increased fishfood production is a secondary stream improvement benefit, but it is rarely a primary objective.

Instream devices can supplement but never substitute for maintaining good hydrologic conditions on the watershed (Wydoski and Duff 1978). Forest practices on the slopes of the watershed, livestock grazing, road construction, flood control, recreational use of land, agricultural-irrigation practices, and mining can negatively affect the suitability of a stream for fish production (Wysoski 1978). When erosion products reach streams, they fill pools, cover food-producing areas with barren materials, destroy cover, increase turbidity, cover spawning areas, and in extreme instances, completely fill the channel. A low-gradient stream may thus deteriorate into a shallow sheet of water largely devoid of fish and insect life.

Following are major categories of stream habitat improvement (White 1975):

(1) Habitat Protection. Prevents deterioration, particularly that which comes from human abuse.

(2) Habitat Restoration. Restores damaged habitat.

(3) Habitat Enhancement. Creates more habitat than would occur naturally.

(4) Maintenance. Maintains restorations or enhancements.

Methods of improving fish habitat fall into the following six major categories:

(1) Treating channels directly by:
    (a) Improving shelter.
    (b) Preventing erosion.

(c) Improving spawning conditions.
(d) Facilitating fish passage.
(e) Removing hazards to fish life.
(f) Improving riffle-pool ratio.

(2) Treating streamsides by:
(a) Planting or manipulating riparian vegetation for cover.
(b) Controlling water temperatures.
(c) Preventing erosion.

(3) Maintaining regulated streamflow by:
(a) Improving headwater areas.
(b) Making releases from existing structures adequate.
(c) Creating controlled storage and release systems.

(4) Maintaining and improving water quality by:
(a) Controlling pollution.
(b) Controlling drainage runoff.
(c) Controlling water temperatures.
(d) Liming.

(5) Controlling undesirable fish species. (Normally a State function but included for information.)

(6) Improving food production by:
(a) Introducing desirable food species.
(b) Altering the stream's physical and chemical conditions.
(c) Fertilizing.
(d) Reducing silt deposition.

Table 1-1 shows the effects of stream habitat improvement on some trout populations in the Northern Central States (White 1975). Research in stream habitat improvements is extensive; Duff and Wydoski (1978) published an indexed bibliography of 828 references that may be consulted.

PLANNING FOR STREAM IMPROVEMENT PROJECTS

A stream improvement plan identifies habitat deficiencies regarding quality and quantity of water supply, cover, and spawning area. As a rule, work on any stream should not be attempted until technical surveys determine the need and the methods. Unless stream improvements are carefully planned by someone with extensive biological training and a thorough knowledge of stream ecology, damage may result (British Columbia Ministry of Environment 1980).

Planning for stream improvement projects should consist of the following:

<u>Analysis of Watershed Conditions</u>. Because soil movement and rapid surface runoff generally preclude success of small fish habitat improvements, the condition and trend of the watershed should be

Table 1-1. Management evaluations of instream habitat by measurements of trout abundance over several years.

Stream, Wild Trout Species, Reference	Primary Management	Schedule of Population Inventories	Effects of Trout Populations and Angling Yield
Lawrence Creek, Wisconsin Brook trout	Bank-cover deflectors in 1 mile (compared with 0.9-mile control)	3 yr before, 3 yr after management	141% rise in age-II+ biomass from better overwinter survival. 156% more fish over 8 in April. 200% greater anglers' catch.
Big Roche-a-Cri Creek, Wisconsin Brook, Brown trout	Bank-cover deflectors in 3.7 mile (compared with 3.1 mile of interspersed control areas), cattle fenced out, beaver dams removed	3 yr before, 2 yr during, 5 yr after management	200% rise in numbers of age-II+, comparing 3 pre- with 3 postmanagement years of similar flow regime in 1.9-mile section of most intensive alteration. Greatest effect was improvement of drought (low-water) abundances of fish. 36% increase in catch per angler hour.
W. Branch Split Rock River, Minnesota Brook trout	Deflectors, bank covers, low dams in 1 mile (compared with 1-mile control area)	3 yr before, 3 yr after management	9-fold increase in numbers of age-0. Doubling of number of age-I+. Angler success rose from 0.58 to 0.89 fish per hour in managed area, while declining in control area.
Hayes Brook, Prince Edward Island, Canada Brook trout	Low dams, deflectors, covers of poles and brush in 0.2 mile (no control area)	5 yr before, 1 yr after management	Number of age-I+ in year after construction was highest on record, nearly double the previous 5-yr average.
Hunt Creek, Michigan Brook trout	Deflectors in 0.3 mile (no control area)	1 yr before, 3 yr after, 3 yr before, 5 yr after management	35% increase in catch per angler hour. Little change in standing (creel census crop).
Pigeon River, Michigan Brook, brown trout	Deflectors in 1.2 mile (compared with 1.2-mile control)	5 yr before, 5 yr after management, then 5 yr after dismantling	Managed-section trout abundance (in terms of fall population plus anglers' catch in previous summer) was originally lower than in control but then rose to equality after management deteriorated when devices were intentionally destroyed.

Table 1-1 (continued). Management evaluations of instream habitat by measurements of trout abundance over several years.

Stream, Wild Trout Species, Reference	Primary Management	Schedule of Population Inventories	Effects of Trout Populations and Angling Yield
Kinnikinnic River, Wisconsin Brown, brook trout	Rock deflectors, rock revetments, fences along 1.4 miles (compared with an unmanaged control)	5 yr before, 3 yr after management	400-500% rise in numbers of brook trout over 5.6 in and 150-200% rise in numbers of brown over 5.6 in, while populations in control area remained essentially static.
Bohemian Valley Creek, Wisconsin Brown trout	Floodwater detention dams, rock deflectors, rock revetments, low dams, fencing in 2.7 miles (compared with 0.7-mile control)	6 yr before, 4 yr after management	Originally negligible brown trout abundance (sometimes fewer than 5 per 0.6 mile) rose to about 250 per 0.6 mile.
McKenzie Creek, Wisconsin Brown trout	Deflectors, bank covers, brush covers, low dams in 3.1 miles (compared with 0.4-milecontrol)	2 yr before, 6 yr after management	10-15% rise in total biomass (25% rise for age-I+, 100% rise for age-II+). Inconclusive changes in numbers of fish larger than 6 in.
Black Earth Creek Wisconsin Brown trout	Fencing, dam removal, few deflectors, bank revetments in 5 miles (control: Mt. Vernon Creek)	3 yr during, 5 yr after management	3-fold increases in age-0, total biomass, and anglers' catch per hour of wild trout. 5-fold increase in spring (pre-angling) numbers of fish larger than 6 in.
Mt. Vernon Creek, Wisconsin Brown trout	Unmanaged control for Black Earth Creek (adjoining drainage basin), dam removed	Concurrent with Black Earth Creek	Relatively minor increases in age-0, total biomass, and anglers' catch per hour of wild trout. 2-fold increase in spring numbers of fish larger than 6 in attributable to hydrologic events.

Note: Table was prepared for publication and referenced in White (1975), but omitted from publication by editorial error.

Source: White 1975

assessed with technical assistance from a watershed specialist. There is no magic formula for determining which watershed conditions ensure success of a stream improvement project. Eroded watersheds should show an upward trend before any structural improvement of the stream channel is made. Excessive water turbidity following light rainfall, scoured channels, silt deposition on stream bottom rubble and in slack water areas, and scarcity of game fish and fishfoods may indicate watershed deterioration.

Stream Habitat Surveys. Fish habitat improvement plans must be based upon adequate stream surveys of physical, biological, and chemical characteristics. The effect of the proposed project on these characteristics then needs to be determined. Frequently, such data are already available from the State fish and wildlife agency. When survey data are not available, State and Federal fishery biologists should be encouraged to participate in the work. They often have specialized equipment not otherwise available, such as that necessary for electrofishing. Detailed instructions should be furnished to Forest personnel for guidance in conducting stream habitat surveys (Platts, Megahan, and Minshall 1983).

Plans. Plans are prepared based on the habitat survey, with details on structures, their specific location, construction methods and materials, and procedures for pre- and post-project evaluation.

Coordination With State Plans. The States are actively engaged in fishery management programs covering a large portion of the National Forest System. Preliminary planning for stream improvement should include contacting appropriate State and Federal personnel to encourage cooperation and to avoid conflicts and duplication of effort.

Coordination of Resource Management. Coordination needs to occur with other resource managers in the area. A memorandum should be circulated among resource managers to inform them about the project and solicit their responses, which should be considered in planning.

Maintenance of Structures. While stream improvement structures are semipermanent in nature, they usually require periodic checkups and necessary maintenance.

Evaluation and Monitoring. To properly evaluate and assess a stream habitat improvement project from a physical and biological standpoint, the biologist must occasionally plan and conduct "before, during, and after" monitoring and evaluations of the habitat and of the response of fish populations (Wydoski and Duff 1978). Good quantitative data and analysis are critical because

Source: White 1975

the results could be the link between the success or failure of habitat improvement decisions made by managers in the future.

FISH SPECIES RECEIVING SPECIAL PLANNING

By law, the Forest Service must protect and improve the habitat of threatened and endangered species found on National Forest System lands sufficient to meet recovery objectives and with minimum impact on other resource programs. The Forest Service also provides habitat management for those sensitive species whose declining populations could result in their becoming threatened or endangered. To avoid further declines in the populations of these species, the Forest Service inventories and monitors their habitat in accordance with plans and objectives for these species. Protection and rehabilitation of waters and watersheds that contain endangered, threatened, or sensitive fish is critical. U.S. Fish and Wildlife Service recovery plans have been constructed for some of these species.

Habitat improvement projects are usually directed at only a few fish species that often represent the habitat conditions needed by other fish species. Table 1-2 shows these key management species recently identified by the Forest Service.

All fish species and stocks present should be considered, or adverse side effects may result (Narver 1976). For example, when a barrier to anadromous fish is removed, resident fish populations above the barrier may be affected. When habitat improvement projects are planned, seasonal and age-specific habitat requirements of the indicator species should be evaluated. Nonindicator species constitute a large portion of our fishery resource and should also be considered by managers and researchers (Becker 1983).

STRUCTURAL CHANNEL IMPROVEMENTS

Structural channel improvements are improvements applied directly to the stream channel. Structural devices in many cases are multifunctional--that is, they improve shelter conditions by creating pools, protect the streambanks from erosive currents, and may form gravel areas suitable for spawning purposes. Channel structures to improve shelter may not be needed in many salmon spawning streams, but are needed in most trout and cool-water streams.

It is essential that a qualified biologist plan the selection of improvement sites and type of structure. Many stream improvement projects are unsuccessful because the biological, geomorphological, and hydrological characteristics of a watershed were either not taken into account or incorrectly assessed in the planning process.

Table 1-2. Forest Service key management species.

Common Name	Scientific Name
Pink salmon	*Oncorhynchus gorbuscha*
Chum salmon	*Oncorhynchus keta*
Coho salmon	*Oncorhynchus kisutch*
Sockeye salmon (Kokanee)	*Oncorhynchus nerka*
Chinook salmon	*Oncorhynchus tshawytscha*
Cutthroat trout	*Salmo clarki*
Rainbow trout (Steelhead)	*Salmo gairdneri*
Brown trout	*Salmo trutta*
Atlantic salmon	*Salmo salar*
Brook trout	*Salvelinus fontinalis*
Lake trout	*Salvelinus namaycush*
Muskellunge	*Esox masquinongy*
Northern pike	*Esox lucius*
Walleye	*Stizostedion vitreum*
Smallmouth bass	*Micropterus dolomieui*
Largemouth bass	*Micropterus salmoides*
Bluegill (Bream)	*Lepomis macrochirus*
Channel catfish	*Ictalurus punctatus*

Consequently, methods well-adapted to one Region may give poor results elsewhere because of differing conditions (for example, when limitations imposed by steep gradients and extreme fluctuations in flow are unrecognized or ignored or abused, watersheds are not treated before or during instream project work). See Figure 1-1 for recommended and nonrecommended stream improvement techniques.

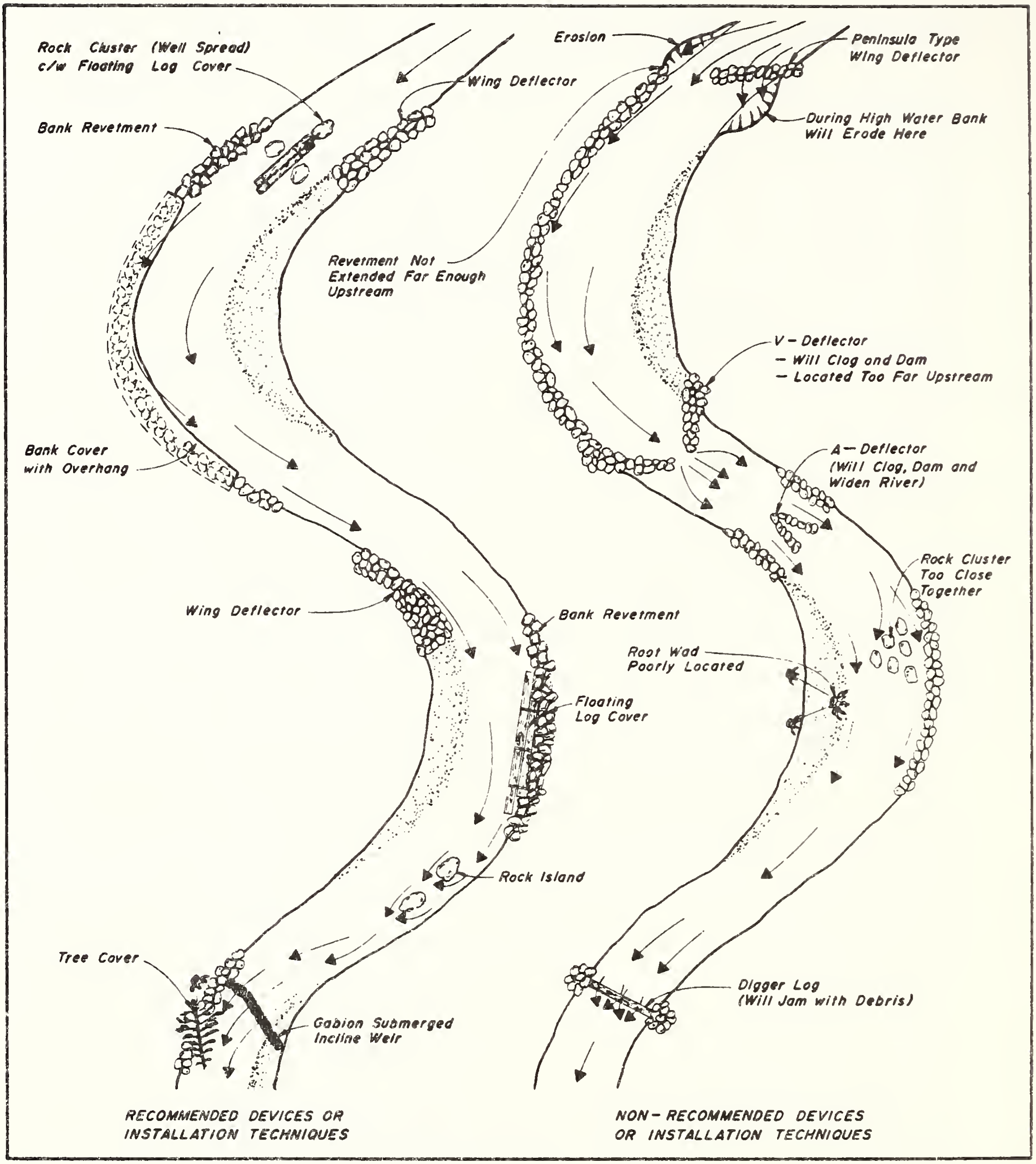


Figure 1-1. Recommended and nonrecommended stream improvement techniques.

Source: White and Bryunildson 1967

Following are guidelines for structural channel improvement:

(1) If the need for improvement is not obvious, existing conditions should not be disturbed.

(2) The installation of most stream improvement structures should be restricted to small streams. As a general rule, unless engineering assistance is requested, cross-channel structures, such as dams, should be restricted to streams whose annual flood volumes do not exceed 200 cubic feet per second. Cross-channel structures can be designed for flows exceeding this amount, but this type of construction is costly. However, bank structures, such as deflectors, may be routinely installed in larger streams.

(3) Structures should not be installed at too-frequent intervals. The unscientific rule-of-thumb that a stream should have a 1:1 ratio between pool (both natural and artificial) and riffle area has proven safe to follow.

(4) Regardless of the type of improvement installed, completed projects should have a nearly natural appearance. Selected sites should offer minimum disturbance of streambanks and vegetation. Upon completing a structure, all evidence of construction work should be eliminated.

(5) Site selection should consider both the primary objective and associated effects of the improvements, particularly hydrological influences on the stream channel.

(6) If possible, selected locations should have natural features that will favor construction. For example, if a log dam is needed, a preferred site would be one in which one or both ends can be braced against rocks. Thus, streambanks should permit keying the ends of structures into them.

(7) Dams are more susceptible to flood damage than are bank structures. Therefore, bank deflectors should be used as alternatives to dams where feasible. Where dams are used, the centers should always be lower than the ends to prevent the stream from cutting around the ends.

(8) The simplest improvement suitable for the purpose should be used, because they offer the least opportunity for adverse side effects (Larken 1974).

(9) Stream gradient should be carefully considered. As a general rule, improvement structures installed on streams with gradients exceeding 3 percent require utmost care. Gabion structures are more adaptable for steeper gradients and larger flows, while log installations are better suited in slow-moving sections and small streams.

(10) Proposed improvement sites should be observed during both low- and high-water periods when planning improvement projects. Under flood conditions, the characteristics of streamflow will often be drastically different from that during low-water periods.

(11) Improvements should be planned in moderation. Planners should avoid concentrating all improvements in one area but rather should strive to place them where they are most needed.

(12) Streambeds should be checked carefully so that structures are not placed where solid bedrock may occur a few inches below the rubble. If structures are placed on bedrock, gas-powered jack-hammers can drill holes into rock for placement of reinforcement rods.

Dams

Dams (also referred to as weirs, sills, check dams, and low barriers) are cross-channel water-retarding devices that for stream improvement purposes serve the important function of creating or improving pools, which provide resting places and shelter for fish and spawning areas for some species. The creation or improvement of pools is a primary objective of stream improvement work. Dams, as well as deflectors, have proved more practical than digging logs, blasting, and mechanical excavation to improve pools.

With proper dam placement, a pool is formed below the dam by the scouring action of water pouring over the dam during flooding. A pool formed above the dam usually loses its value once it becomes filled with rubble, gravel, and other streambottom materials during peak runoff. The upper pool should never be more than five times longer than the channel width (White and Bryunildson 1967).

Most dam failures result from the pool below the dam becoming so deep that portions of the streambed immediately above the dam loosen and wash down under the dam. With log dams, this sometimes leaves the logs high and dry some distance above the stream channel. Rock dams merely slide into the hole scoured on the downstream side. To prevent this, special construction is necessary to stabilize the streambed on the upstream side of the dam. Another important cause of failure is improper construction at the ends of the dam. Unless structures built of logs are braced behind trees or large boulders, it is necessary to extend them at least 4 to 6 feet into the bank (Wydoski and Duff 1978). Because distance into the bank is a function of stream fluctuation, it is not necessary to extend structures as far back as 4 to 6 feet on low-gradient, stable streams.

High dams are much more subject to destruction by floods than low ones. Since the main benefit from dams is the scouring effect of water that passes over the crest, and the pool above is of lesser concern, it is not necessary that they be built very high. Dams

constructed about 12 inches above the level of the stream bottom are usually adequate for scouring pools.

Dams should never be built so high that floodwaters will be forced over the bank at either end. This is extremely important because dams reduce the gradient of the stream channel thus increasing the cross section of the flow. Rock riprap banks usually should be rock riprapped at both ends. Width and location of dams are important. Using straight sections of narrow channels reduces costs and possible damage. Dams in the Northwest used for gravel accumulation and pool formation may be placed in areas with relatively wide cross sections. One must weigh the cost of a larger structure in a wider channel against the potential destructive forces of high flows in a narrow channel acting on the dam.

Constructing or directing the flow through notches greater than one-fourth the total width of the dam may be desirable. This will help provide the digging action needed during low-flow periods. Other structures, such as deflectors, should be used where increased scouring is desired. Dams should not be used in streams where maximum summer temperatures may be critical. In low-gradient streams, the water should be kept moving; deflectors rather than dams should be used so as not to impede the current unnecessarily (White and Bryunildson 1967).

Log Structures

The most successful Forest Service instream structures are the single- and double-log plunge pool structures, with the single-log type used most frequently. These structures can be used most successfully on streams ranging from 2 to 20 feet in width with stream gradients between 0.5 to 20 percent and annual maximum discharge below 200 cubic feet per second (ft^3/s). Logs from many tree species can be used, ranging from aspen and pinyon-juniper to spruce and fir. Log sizes typically range from 9 to 15 inches in diameter. Log lengths can vary depending on stream width, but all logs should be cut long so that a minimum of 4 to 6 feet of the log's length can be buried in the streambank on each side (Duff 1980). Large logs (up to 4 feet in diameter and 66 feet long anchored 13 to 17 feet into the streambank) have been installed successfully in a stream on the Umatilla National Forest in eastern Oregon (Reeves and Roelofs 1982).

<u>K-Dam</u>. The K-dam (Figure 1-2) is so named because the knee braces used at each end, when viewed from above, give the dam a letter K shape. Logs, called mudsills, are placed beneath the dam parallel to the streamflow and furnish the base on which the upstream face of the dam is constructed. The K-dam is highly reliable when properly installed. Generally, installation cost is less than for log and board dams because less excavation is required. As with

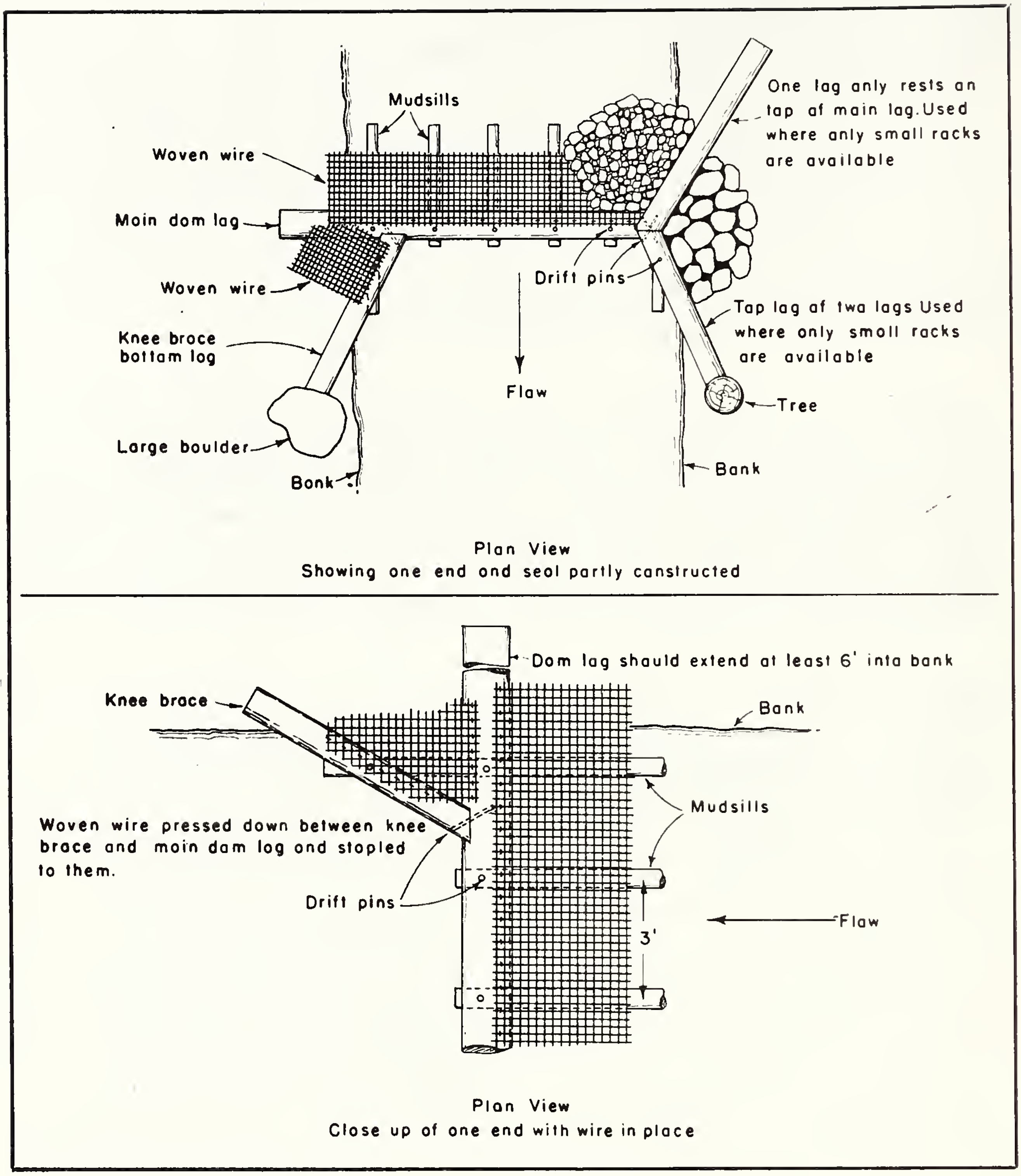
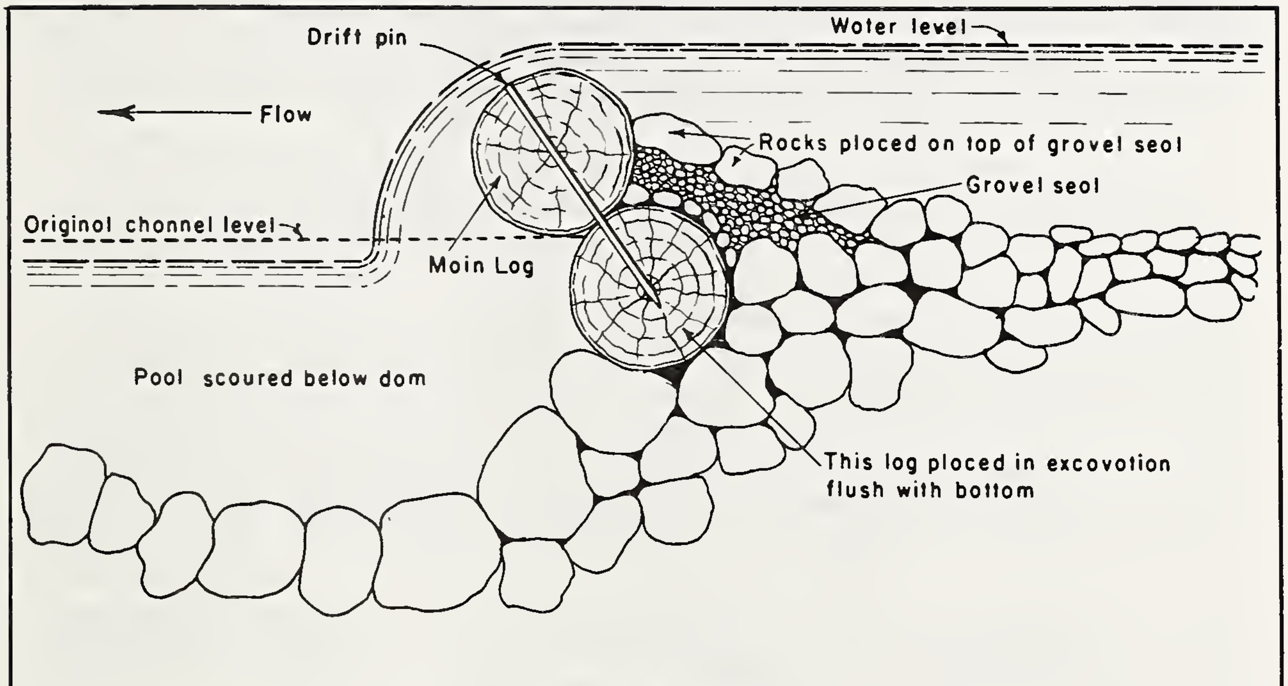


Figure 1-2. K-dams.



Cross Section
Should be used only where excessive undercutting beneath dam is not expected

Figure 1-2 (continued). K-dams.

all log dams, narrow channel widths, low stream gradients, and low volume flow requirements should be emphasized.

Construction begins with excavations for the ends of the dam and the mudsills. The ends of the dam are placed 6 feet or more into the bank; the excavation for the mudsills should be at least one-half of their diameter. Mudsills should not be spaced farther than 3 feet from center to center.

In streams of small flow, it is possible to place the mudsills in position first and then lower the main dam log on top of them. However, if there is a sizable volume of water to work in, it is easier to place the main dam log in position first and then slide the ends of the mudsills under the log (USDA Forest Service 1952).

After the mudsills and dam log are in place, galvanized hog wire is stapled on woven wire to the top of the log and pressed into place against the mudsills to which it is also stapled. The galvanized wire should extend up on the banks at least 3 to 4 feet and into the bank excavations at the ends of the dam. The wire below water level may be covered with fiberglass filter cloth to aid sealing the structure. Next, wire is carefully placed on a layer of rocks of a larger diameter than the openings in the wire. This layer of rocks is covered with a thick seal of water-washed gravel and carefully tamped in around the ends of the log extending into the bank excavation. Application of this gravel seal is begun at the ends of the dam and worked toward the center of the stream. Finally, the gravel seal is given a protective covering of large rocks to prevent it from being swept away in high water. Figure 1-2 shows in detail how the dam is sealed.

Knee braces are installed as shown in Figure 1-2. These are unnecessary where the main log is braced behind trees or large boulders. The knee braces are drift-pinned securely to the main log, and extended into the banks for good, sound footing. Next, woven wire is stapled to the knee brace, and the wire is forced down into the opening between the knee brace and the streambank. One edge of the wire is then stapled to the main dam log, and the pocket that is created is filled with carefully laid large rocks. The floor of this pocket may be given additional strength by extending forward the mudsill at the end of the dam. Rock work is begun with the knee brace as a toe and extended up and over the end of the dam.

Where only small rocks are obtainable, it is often desirable to build up the knee brace with another log and construct a cribbing by extending a log upstream as shown at the right end of the dam in Figure 1-2. This should be used only where necessary as it looks artificial and detracts from the natural appearance of the site (USDA Forest Service 1952). Rock work at the ends of the dam should extend up the banks above high-water level. When the dam

fills, the water should pour over the full length of the log between the knee braces. This keeps the entire log wet and thus less subject to rot.

Modified K-Dam with Double-Wing Deflectors. The modified K-dam with double-wing deflectors is designed for small streams with average annual flows of 1 to 5 ft^3/s. Instead of knee braces on the downstream side of the dam, wing deflectors are installed upstream (see Figure 1-3).

The dam consists of one or more logs (depending on stream depth) held in place by four steel posts. Eight posts should be used if the dam is more than one log high or if the stream is more than 10 feet wide. Posts are placed close to the banks on each side of the dam. Wire is wrapped around one post, across the log, and around the other stake. Stakes are driven in until the logs rest firmly in the stream bottom. The dam is notched with the downstream side narrower and slightly lower.

The dam is notched to hold the wing deflectors. Half the portion of the deflectors that overlaps the dam increases spillway capacity during high flows. The deflectors are staked to the dam and held in place with steel posts and wire in the same manner as the dam. Rocks are placed and packed with sod in the areas behind and in front of the deflectors to deter undercutting and bank erosion. The logs may be pretreated to retard rotting.

Wedge Dam. Wedge dams are constructed with the apex facing upstream (Figure 1-4). The same techniques used in constructing and sealing K-dams are used with wedge dams. The wedge dam offers the following advantages over K-dams: the point of the wedge can be installed lower than bank ends of logs, resulting in less maintenance; the stream can be spanned with two shorter logs as opposed to one long log; and less digging is necessary to secure ends of logs into banks 4 to 6 feet (Lewis 1980). Wedge dams are less prone to washout than are K-dams (Seehorn 1980).

Board Dam. Boards can be used in place of mudsills and woven wire in the construction of log dams. Although this is a more expensive method of construction, it is highly effective on streams where the flow is very small. Board dams are best suited to rocky streams where the banks can be excavated to strata sufficiently hard to support the weight of the dam. Very short spans are also recommended because there is no support to the main dam log except at the ends. Under these circumstances, it is much easier to make dams watertight using boards.

Board dams require special construction, as shown in Figure 1-5. Construction costs can be reduced if heavy equipment, such as a backhoe, can be used to do the excavation work. The main dam log is held slightly above the channel level of the stream by keeping

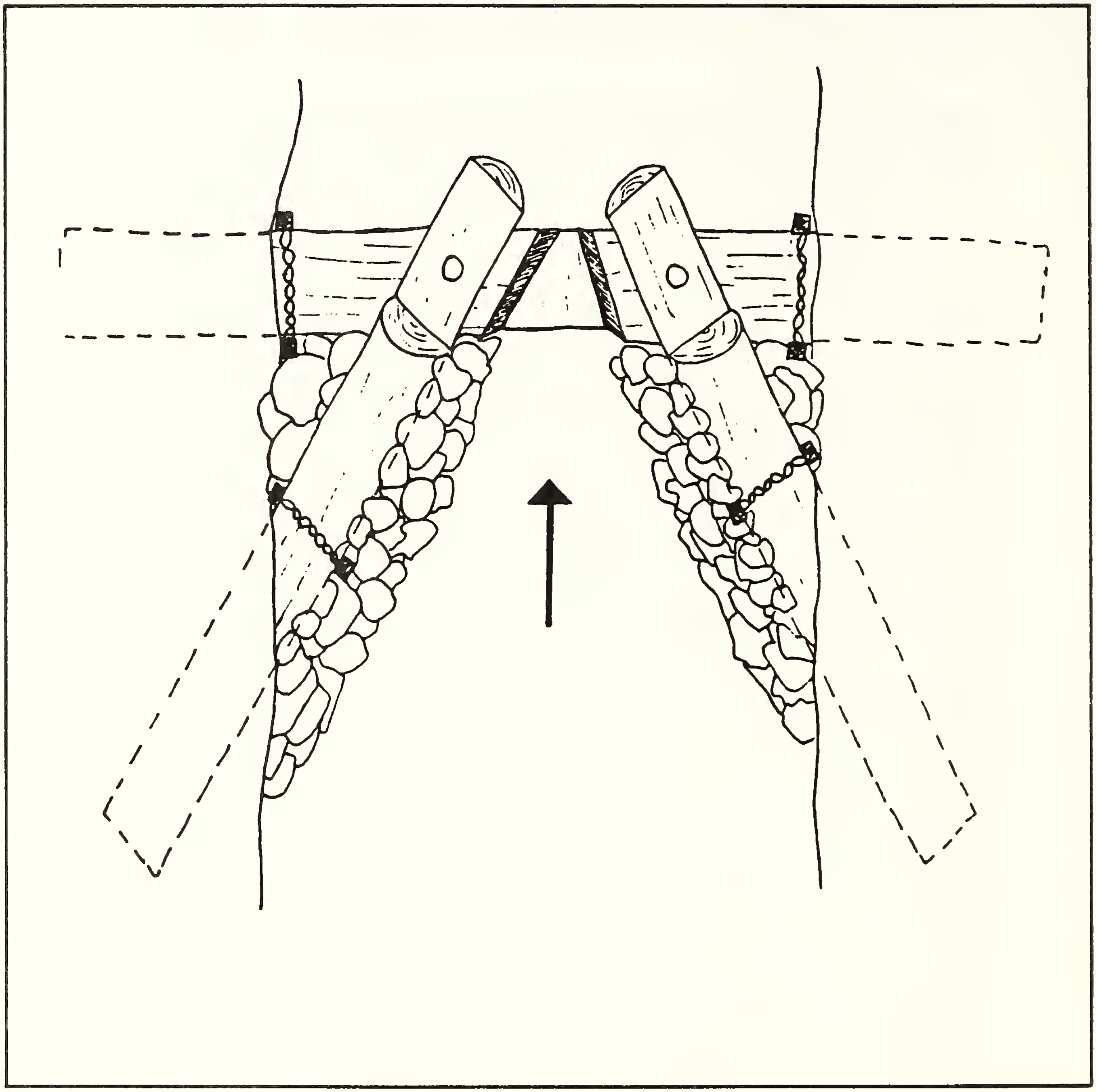


Figure 1-3. Modified K-dam with double-wing deflectors (view from above).

Source: Baily 1982

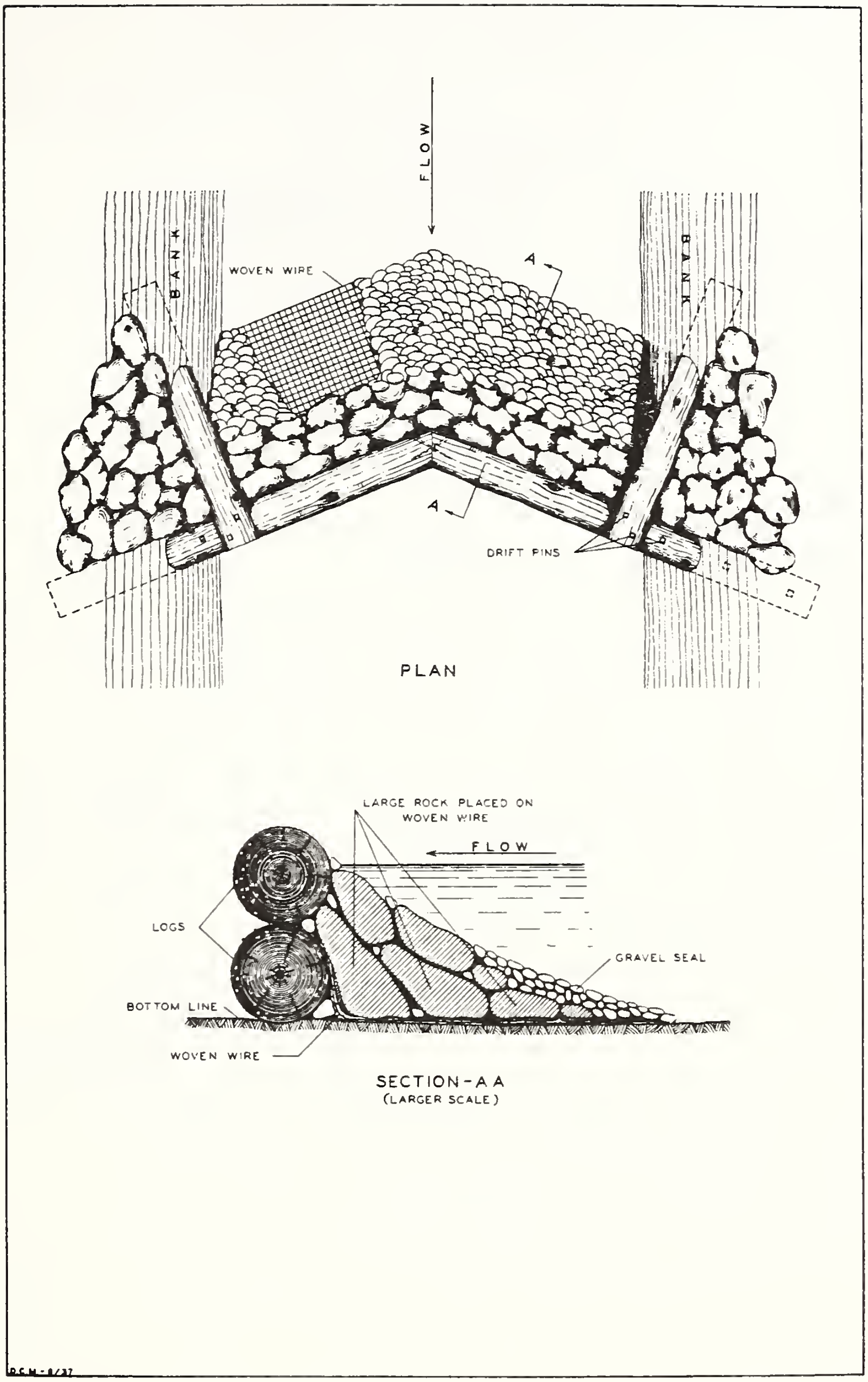


Figure 1-4. Wedge dam.

Source: Seehorn 1980

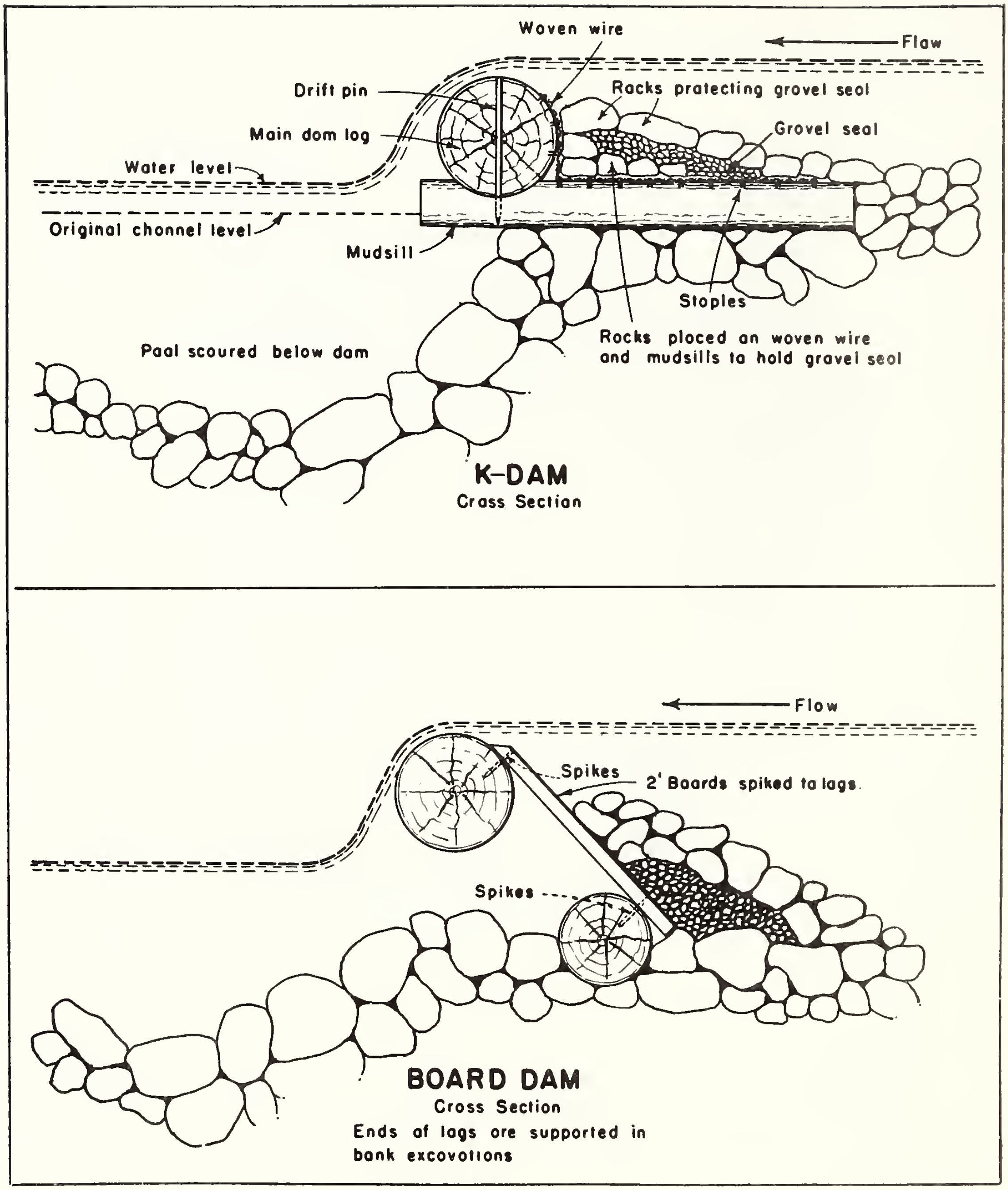


Figure 1-5. Board dam.

the bottom of the bank excavations higher than the channel level. Boards are nailed flush with the top of the main log and supported on the lower end by a log placed on the stream bottom. Boards are extended into the excavations in the banks for a short distance. The bottom ends of the boards are cut to conform to the unevenness of the stream bottom. A gravel and rock seal is essential with this dam, the same as with other types of dams. Construction at the ends of the dam is the same as for the K-dam.

Green rough lumber, at least 2 inches thick, is satisfactory for board dams. Dry lumber must be soaked before using so that it will not expand and buckle after being nailed in place. Although many woods are suitable for this and other types of stream improvement construction, poplar, aspen, and related species should be avoided because they lack strength when wet.

Jack Dam. Jack dams (also called flow channel structures in the Northeastern United States) are a type of board dam. Jack dams consist of an upstream log placed in a trench at least as deep as the log's diameter, a downstream log placed on top of the stream bottom and 5 to 8 feet below the upstream log, double flooring nailed between the two logs, and a stone-filled wingwall on each side (Figure 1-6) (Miller 1980). Heavy black plastic may be placed between the two layers of flooring and into the trench dug for the upstream log to help prevent leaks through the dam. The wingwalls narrow the stream to concentrate the flow to dig a hole below the dam and protect the ends of the structure to prevent the stream from washing around the device. The drop should be about 12 to 16 inches. The wingwalls and upstream and downstream logs should extend 4 to 6 feet into both banks and be pinned to the bottom with reinforcement rods. Frequently, the instream side of the wingwalls are faced with planking. The wingwalls should be filled with stone and a large stone placed on the banks at the upper end of the wingwall to help control erosion.

Simple Log Dam. Where flooding is not severe and the bottom materials are not subject to excessive scouring, dams may be constructed by spanning the stream with one or two logs (Figure 1-7). The construction differs from the K-dam in that the galvanized woven wire and mudsills in the seal are eliminated and are replaced with a bottom log placed slightly upstream from the main dam log and flush with the streambed. Other features of the simple log dam are essentially the same as those for the K-dam, though the knee braces may be eliminated if the banks are hard and large rocks are available for the construction at the ends of the dam.

Simple log dams should be used only where excessive undercutting will not result in loss of the seal. Standard K-dam construction using mudsills and woven wire or boards is usually the best guarantee against this in doubtful cases.

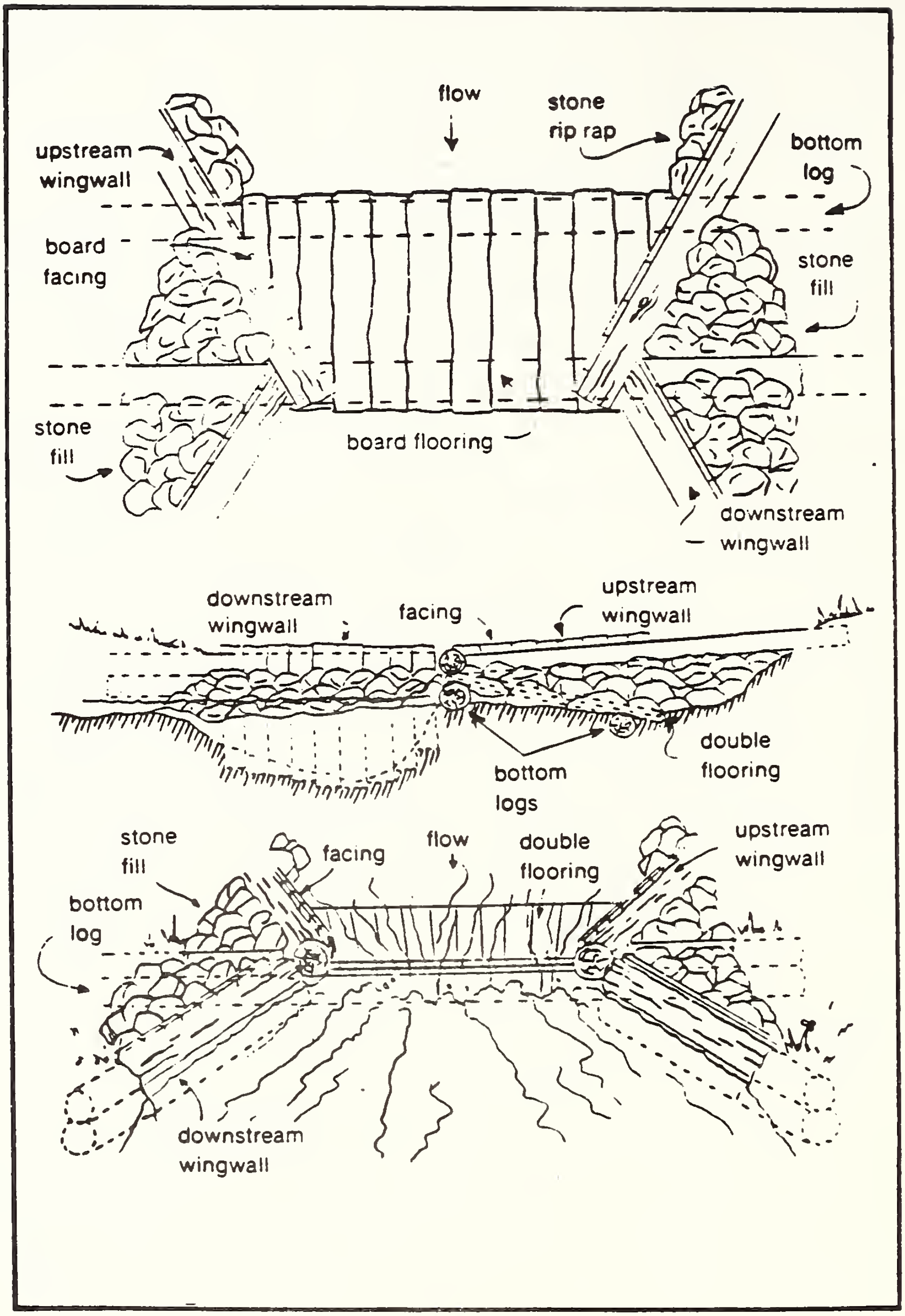


Figure 1-6. Jack dam.

Source: Miller and Tibbott 1980

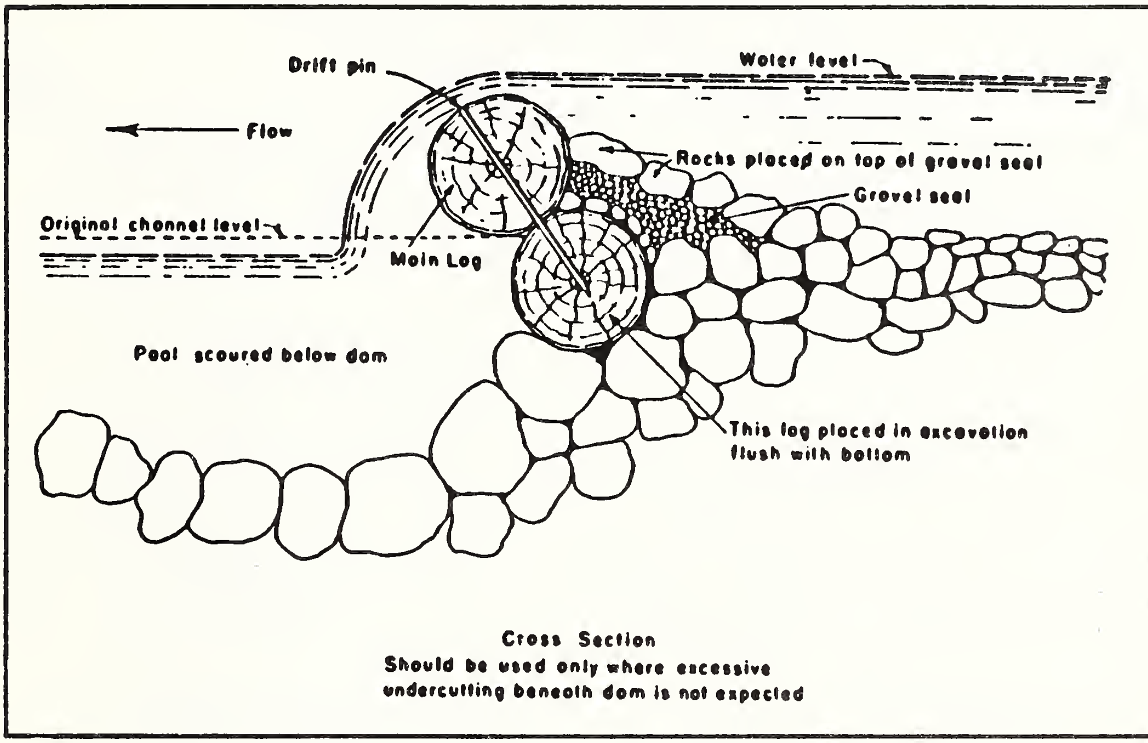


Figure 1-7. Simple log dam.

Hewitt Ramp. The Hewitt ramp is a pool-forming device, usually made of logs and timber, constructed on relatively stable, steep-gradient streams with firm channel bottoms (Figure 1-8). The log forming the ramp crest must be securely anchored into the banks on both sides of the stream and ballasted with rock. Since wood decays, an alternate ramp constructed of selected rock shapes can be used (Figure 1-8) (British Columbia Ministry of Environment 1980). With the rock ramp, it is important to ensure that the rocks forming the downstream weir are oblong in shape to maintain stability even when undermined by the plunge pool.

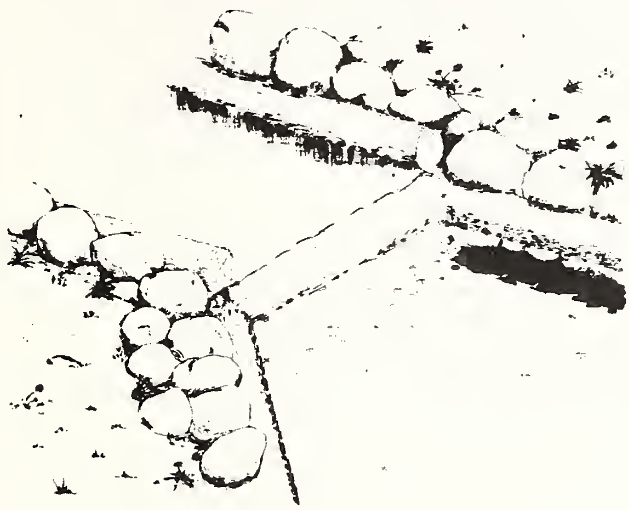
Rock and Wire Structures

Gabion Dam. Gabion dams are very effective under certain conditions. Gabion baskets provide a basis for massive block-type structures that are well-adapted to medium and fast-flowing streams. Because of their design, the baskets are highly flexible, thus allowing structures to sag, bend, and twist in order to conform to stream channel configuration without breaking. Gabions have been used most efficiently in streams 10 to 20 feet wide, with a stream gradient between 0.5 and 1.5 percent and a maximum discharge below 2,000 ft^3/s. Gabions have been used successfully in the Pacific Northwest in wider channels with higher discharges. Streams with gabion structures average a summer low-flow discharge from 5 to 10 ft^3/s, enough to keep the structures operational. Under these conditions, Duff (1980) finds that most plunge pools created were high quality ranging in depth from 4 to 8 feet. Although life expectancy of gabions currently is unknown, under most conditions they may last as long as 50 years.

Unassembled gabion baskets are relatively lightweight and easily transported by helicopters to remote areas. These structures are particularly well-adapted to remote stream sections where log materials are scarce and rock abundant.

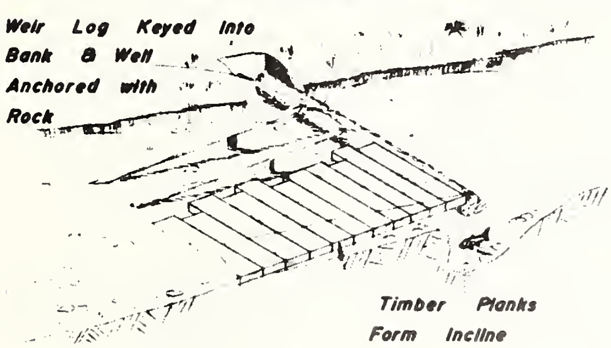
Gabion dams are extremely effective in protecting streambanks below culverts that accommodate large and high-velocity discharges. In addition, gabion dams are effective in creating pools at culvert outlets to help fish pass.

Gabions are comparatively expensive. Labor and material costs for these installations generally exceed those for log structures, particularly when rockfill must be quarried and hauled. Double- or triple-coated galvanized woven wire is best. Another disadvantage to rock and wire structures is the unnatural appearance. However, the high initial cost may be offset by low maintenance cost and permanency, particularly where damage to stream channels has occurred from floods or highway construction. A more natural appearance can be created by covering the tops of gabions with dirt and seeding to grass.

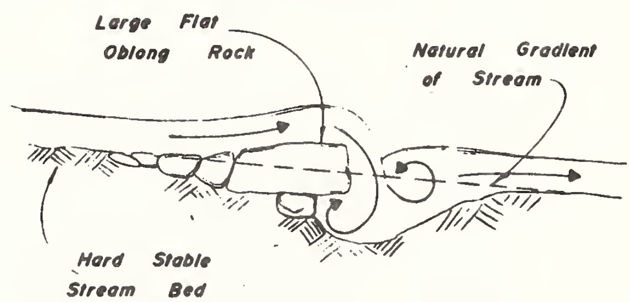


HEWITT RAMP IN OPERATION
(Log Constuction)

HEWITT RAMP IN OPERATION
(Rock Construction)



HEWITT RAMP CONSTRUCTED
WITH LOGS AND TIMBER



CROSS SECTION OF
HEWITT RAMP
(Rock Construction)

Hewitt Ramp constructed of logs and timber. Undercut plunge pool forms downstream and is readily passable by both upstream and downstream migrants. This device must only be used in small, high gradient streams to avoid deposition of silt and debris upstream.

Modified Hewitt Ramp utilizing selected natural stone or quarry rock. Large, flat, oblong rocks form weir crest to permit undermining caused by plunge pool. This device must only be used on small, high gradient streams.

Figure 1-8. Hewitt ramp.

Source: British Columbia Ministry of Environment 1980

Gabion dams should be constructed on comparatively level bases or set in excavated trenches for maximum stability. Dams built in streams should be protected with small bottom materials by constructing splash aprons. However, to ensure a good pool at all times, dams should be constructed with aprons, as shown in Figure 1-9. Where possible, the entire structure, or successive layers, should be assembled together and stretched in place before filling with rock. This procedure ensures best possible positioning and simplifies fastening baskets together.

Anchor or wing sections should extend 6 to 12 feet into the banks, depending on types of bank materials. Maximum anchor lengths should be used when dealing with banks composed of sand or gravel. To minimize loose fill along the wings, the excavation for anchor sections should be dug only as wide as the basket itself. As an economy measure, baskets should be used that have fractional depths of 12 or 18 inches for anchor sections as shown in Figure 1-10.

For best results, rocks should be hand-placed in the baskets. When machine-filled, loss of fine and small rocks cause sagging and collapse of individual units. Hand filling can be expedited by using heavy equipment to place rockfill in a convenient location. Basket lids should be closed in a downstream direction to prevent floating debris from snagging and ripping them open.

Dams should be water-tight to facilitate fish passage in low-water periods. If the entire waterflow filters through the structure, fish migration is blocked. This problem can be easily remedied: window screen, fiberglass filter cloth, heavy tar paper, or plastic sheeting can be placed on the inside face of the downstream wall of the gabion basket before filling it with rock. Liberal amounts of straw, leaves, and twigs are less effective for trapping fines. Experience has shown that when large, round rock is used to fill baskets, a back pressure is sometimes built up inside the wing sections causing collapse and washing away the fill materials around the wings. This is particularly true when fill materials around wings are composed of sand and small gravel. Therefore, take care to add straw, leaves, twigs, or other materials to wing sections to prevent back pressures from occurring.

Concentrating overflow, if desirable, can be done in several ways. Table 1-3 shows one method in which fractional baskets are used. In most cases, the overflow is concentrated by arching the dam in a vertical plane by simply excavating the foundation slightly deeper in the middle of the dam. Because baskets are flexible, they allow for some sag without weakening the total structure (see Gabion Deflectors and Trapping Existing Gravels in this chapter).

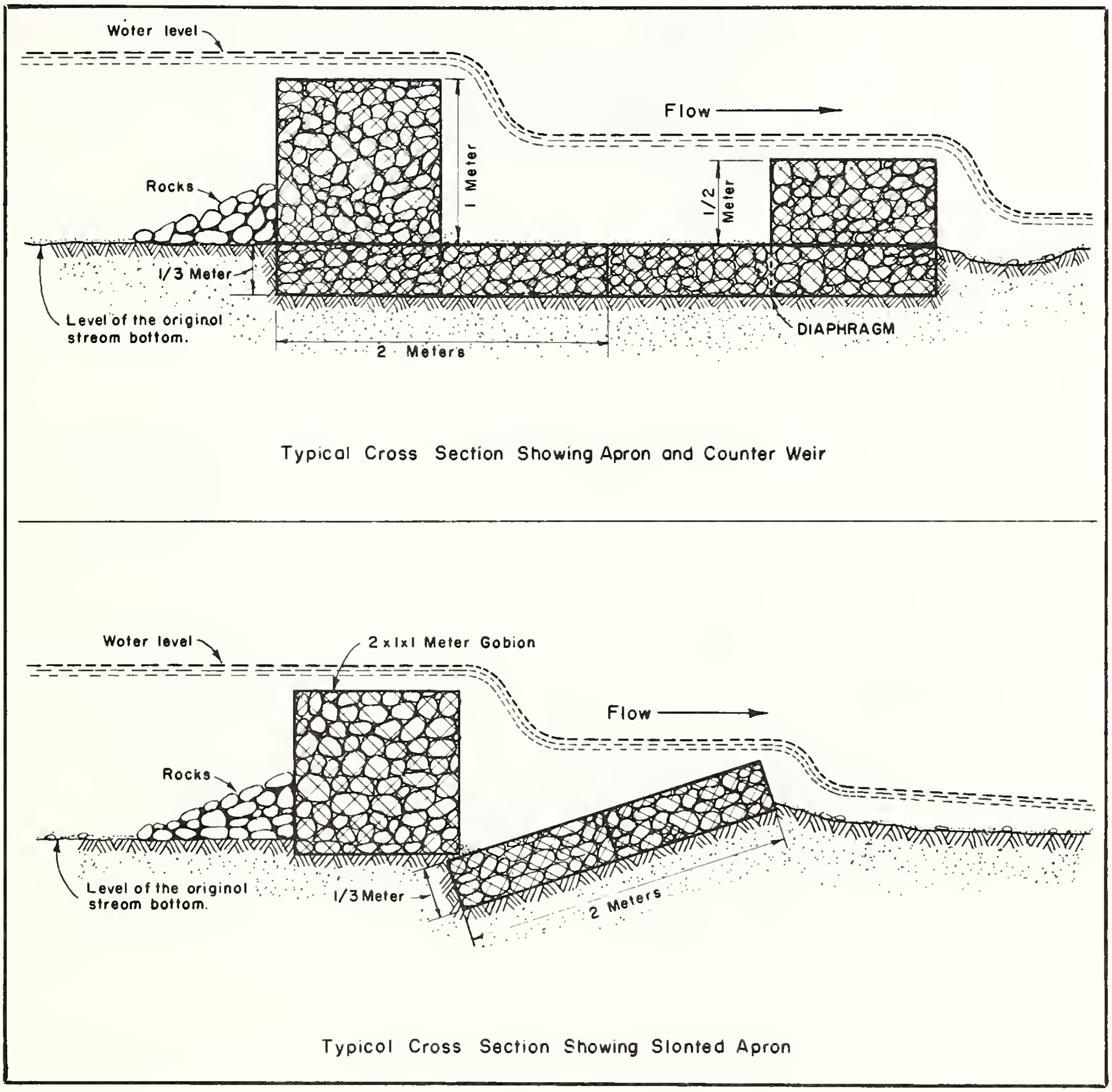


Figure 1-9. Gabion dam (with apron).

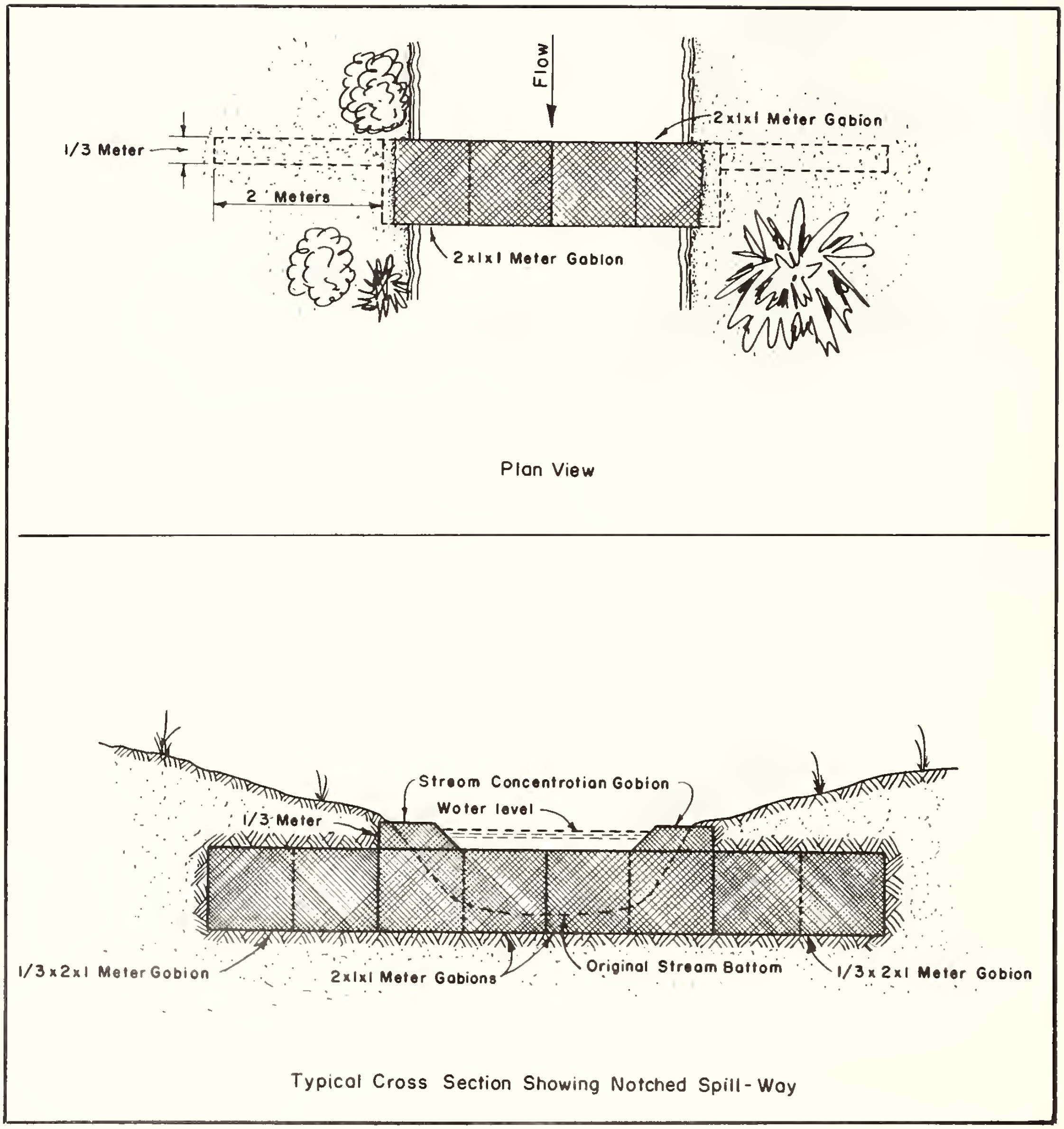


Figure 1-10. Gabion dam (with notched spill-way).

Table 1-3. Standard sizes of gabion baskets (feet).

Length-Width-Depth	Number of Diaphragms	Capacity (cubic yard)
6'6" x 3'3" x 3'3"	1	2.616
9'9" x 3'3" x 3'3"	2	3.924
13'1" x 3'3" x 3'3"	3	5.232
6'6" x 3'3" x 1'8"	1	1.308
9'9" x 3'3" x 1'8"	2	1.962
13'1" x 3'3" x 1'8"	3	2.616
6'6" x 3'3" x 1"	1	0.785
9'9" x 3'3" x 1"	2	1.177
13'1" x 3'3" x 1"	3	1.570

Trash-Catcher Dams. Trash-catcher dams (Figure 1-11), constructed using woven wire and fence posts, are relatively simple and inexpensive structures that are well adapted for low-gradient streams (streams 3 to 20 feet wide with a stream gradient of 0.5 to 5 percent and discharges below 150 ft^3/s). Plunge pools typically form depths of 2 to 4 feet. Trash-catcher dams are not desirable for use in small mountain streams with gradients exceeding 5 percent or where subject to major spring and summer storms. Within a short time period, accumulated trash gives the appearance of a natural debris jam. However, a major disadvantage of the trash-catcher dam is its susceptibility to ice damage.

Selected sites should be restricted to those with stream gradients of less than 3 percent. Locate all sites on straight reaches of the stream. Locations should take advantage of tall bank vegetation to provide shade and cover. Trash dams should never be installed in shifting alluvial deposits, because shifting sand and gravel cause an abrasive action that wears and weakens the woven wire.

After the proper location is selected, streambeds are excavated for anchoring the structure. Excavation should extend a minimum of 3 feet into each bank. Next, the end posts are driven into each bank excavation. Normally, these posts should protrude about 12 inches above the bottom of the excavation. A wire or cord is then tied to the top of the end posts to use as a guide to drive the intervening posts. Intervening posts are driven so that the tops of the posts form a depressed profile (Figure 1-11). Center posts should not extend more than 6 inches above the streambed, particularly in streams with heavy icing conditions. Spacing should be about 2 feet between posts.

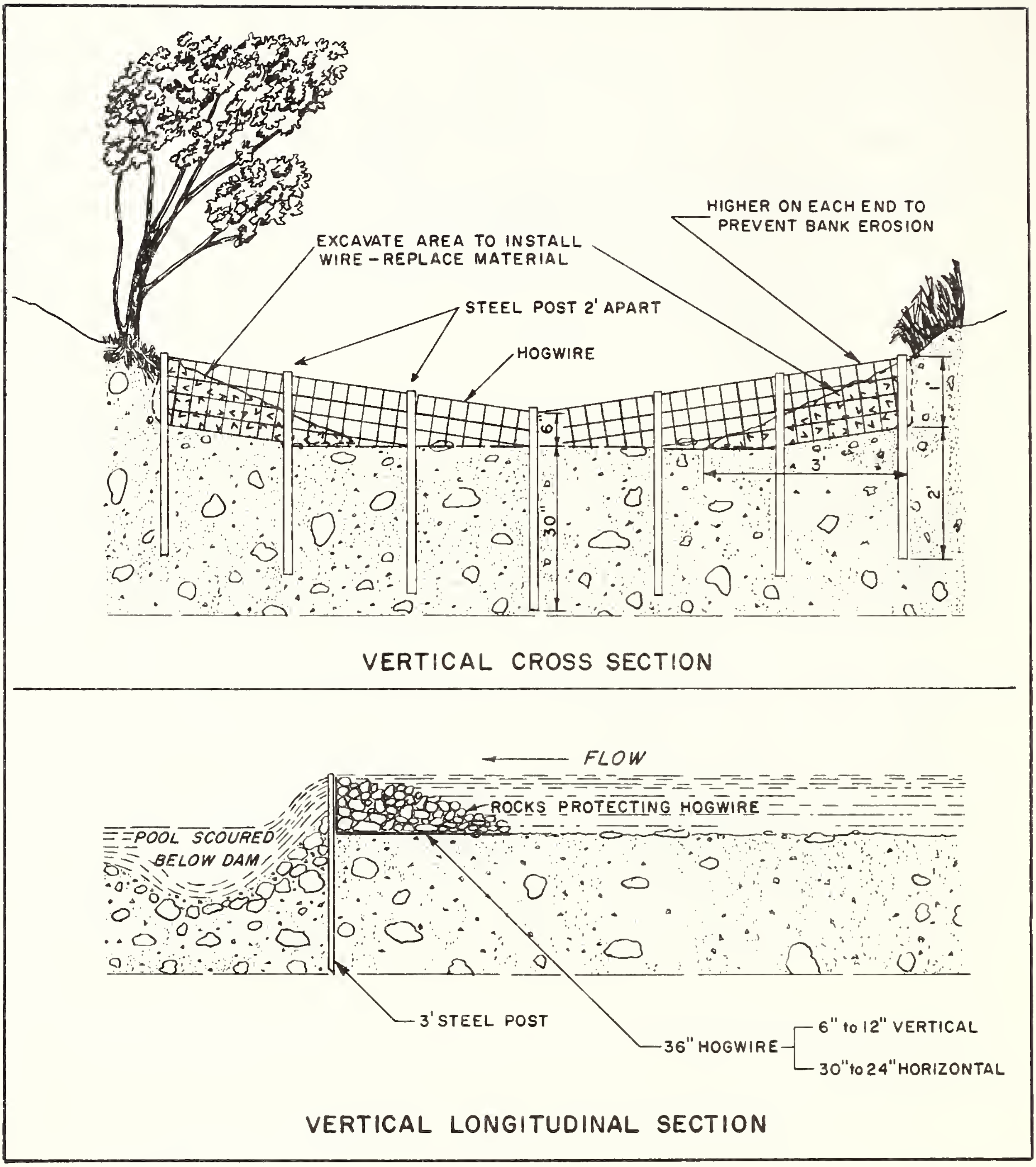


Figure 1-11. Trash-catcher dam.

After all posts are in place, double- or triple-coated galvanized woven wire is placed along the upstream side of the posts as shown in Figure 1-11. The wire is then fastened to the posts, starting with center posts and progressing toward each bank. After the wire is in position, large rocks are placed on top of that portion that extends upstream. In areas where icing occurs, rocks are piled level with top of the wire. If readily available, debris scattered in the stream above the dam will accumulate, starting the dam's functioning. Plastic sheeting also will serve this purpose. When the dam is completed and functioning properly, the main water overpour will be concentrated in the center of the structure.

Rock Dams

Rock dams (Figure 1-12) are easy to construct and extremely effective and natural in appearance in small streams 5 to 12 feet wide with a stream gradient between 0.5 to 2 percent and high flows not exceeding 120 ft^3/s (Duff 1980). Rock dams have been used in wider channels with higher peak flows. Rock dams are very suitable where large rocks are obtainable (typically 1 to 3 feet) and flooding is not severe.

Only large, oblong rocks at least 4 feet long should be used, with the longest axis of the rocks parallel to the streamflow. Rocks of this size are necessary to permit scouring (Figure 1-12). Using in-place large boulders in the streambed or on the banks, and keying rocks into these boulders as shown in Figure 1-12, always results in better construction. Where suitable natural boulders in place are not available, it is desirable to build the dam in the form of an upstream arch, greatly increasing the strength of the dam.

Rock dams should be kept low to avoid flood destruction, and they should be sealed with small gravel and rock as with other dams. Ordinarily, the streambed should not be disturbed to any extent in the construction of rock dams, as it is necessary to key the construction rocks to the bottom as well as to each other. Disturbing the bottom makes the base unstable, which may cause it to shift during high-water periods, resulting in damage to the dam.

Rock construction should be extended at the ends of the dam up onto the banks to provide an expanded flood runoff spillway. Smaller rocks should be used for this purpose, but they should be carefully placed.

Concrete Weirs

Because concrete is unattractive, its use is limited to foundations for bank covers or wing-deflectors. It should not be used as an exposed external material because it would ruin the natural appearance of streams.

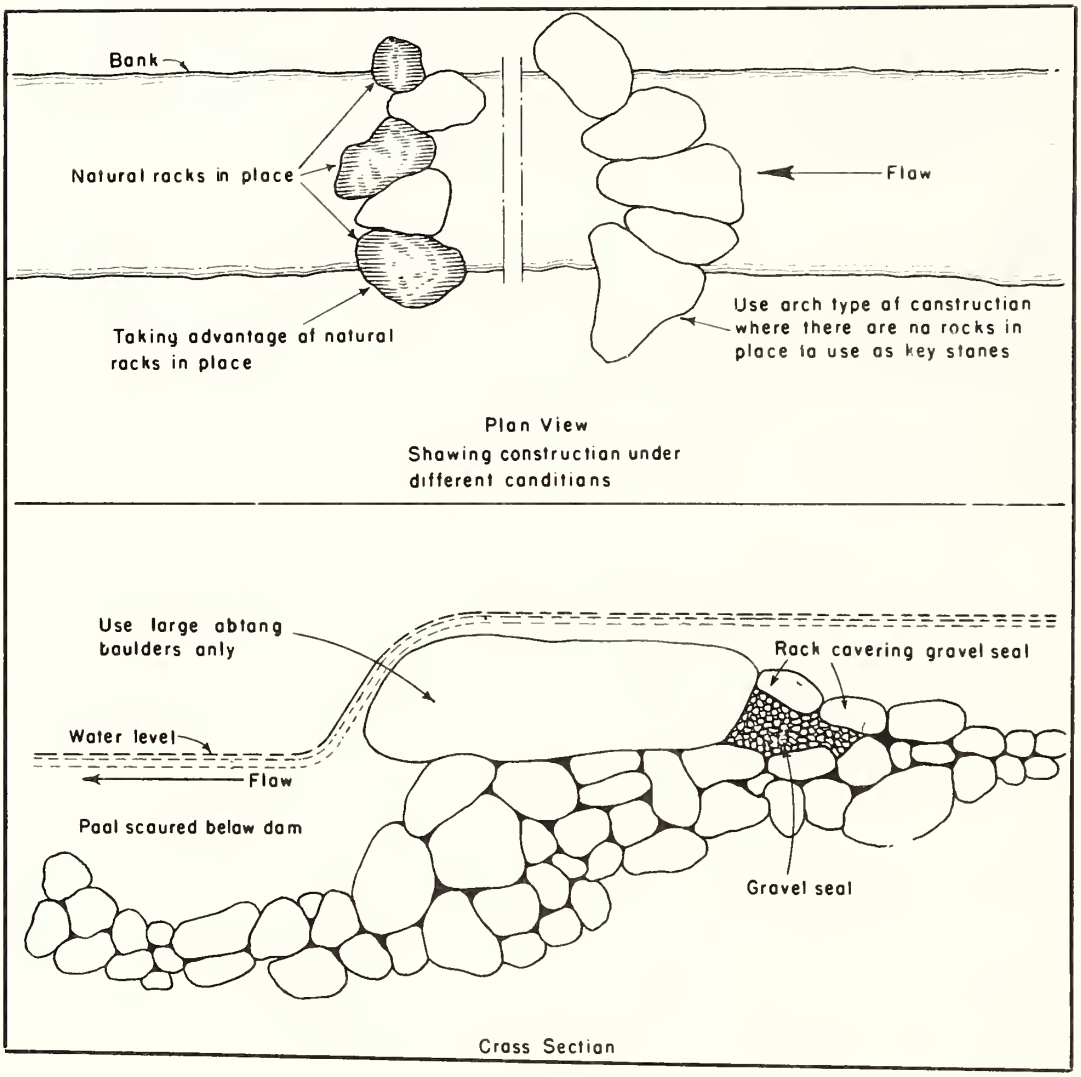


Figure 1-12. Rock dam.

Channel Blocks

Where there is a split channel, neither branch may contain enough flow for desirable fish habitat during periods of low flow. The channel providing the best habitat should be retained and the other one blocked, forcing the entire normal flow into one channel. A channel block consists of a rectangular framework of wood. Parallel logs 4 to 6 feet apart are placed across the opening of the channel to be blocked. The ends should extend 4 to 7 feet into the bank. Logs are pinned to the bottom with reinforcement rods. Cross logs, angled downstream, are pinned to the base logs and the crib structure is filled with stone (Figure 1-13). If more height is needed, additional face logs and additional cross logs may be added. The completed structure should be lower than the existing bank. The blocked channel can serve as an overflow channel and help prevent overbank flooding during periods of high flow (Miller and Tibbot 1974). Large rocks should be placed in the blocked channel immediately behind the structure to prevent high water flows over the device from digging a large pool. Gabions can be used successfully to block side channels (see Figure 1-13). Various deflectors can be used in place of channel block to divert flow away from side channels.

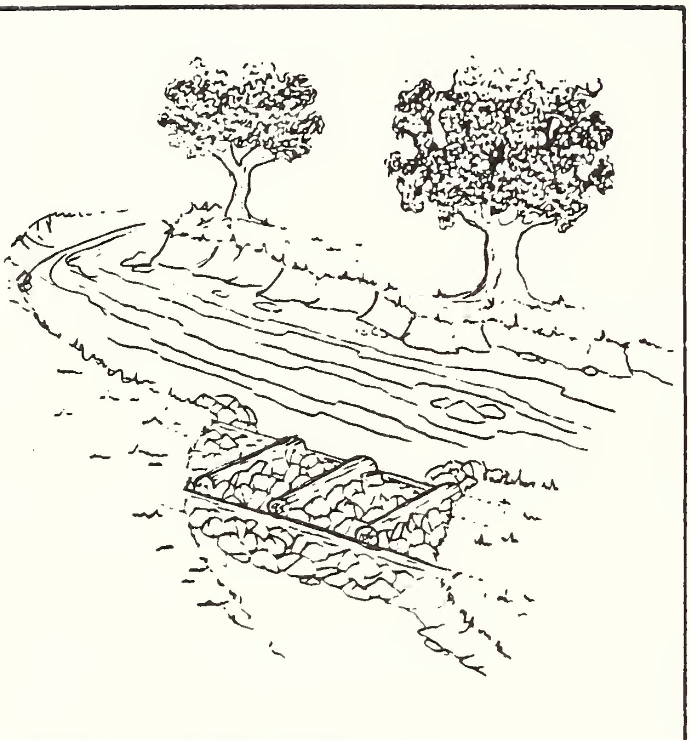
Deflectors

Deflectors, sometimes referred to as wing dams or jetties, narrow and deepen streams, encourage meandering, protect eroding banks, cut off undesirable side channels or direct the flow to a more suitable channel, and create pools.

Where they can be used effectively to create pools, deflectors are preferable to dams (White and Bryunildson 1967). When properly installed, they are less subject to destruction than dams, and they are generally less disturbing to the stream bottom (Figure 1-14). Deflectors installed to form a pool will scour a hole in the bottom and deposit the material to one side of the stream where it is usually exposed during periods of normal low flow. Vegetation can be established on this deposit or island, and this area can be maintained whether or not the deflector remains in place.

By comparison, if a dam should be damaged or destroyed, there is a violent disturbance to the streambottom resulting from the downstream movement of the material deposited above the dam. This is harmful to insect and other animal life so important as fishfood. Dams have a double effect on stream bottoms: the channel is filled above the dam and scoured below the dam. The materials disturbed, in both instances, remain in the stream channel and are subject to the continued action of the water during both high and low stages.

The use of deflectors to protect eroding banks and to cut off side channels is shown in Figure 1-14. Gabion deflectors are satisfactory for this purpose in hard-bottom streams with large flows. On



In a situation where a stream has been divided into two or more channels, a channel block can be constructed to divert the available water into one channel. The channel providing the best fish habitat should be retained to receive the water. A rectangular framework of wood is the basis for a channel block. The bottom logs are pinned into the streambed, with subsequent logs pinned to the bottom one. The solid unit thus formed is then filled with large stone.

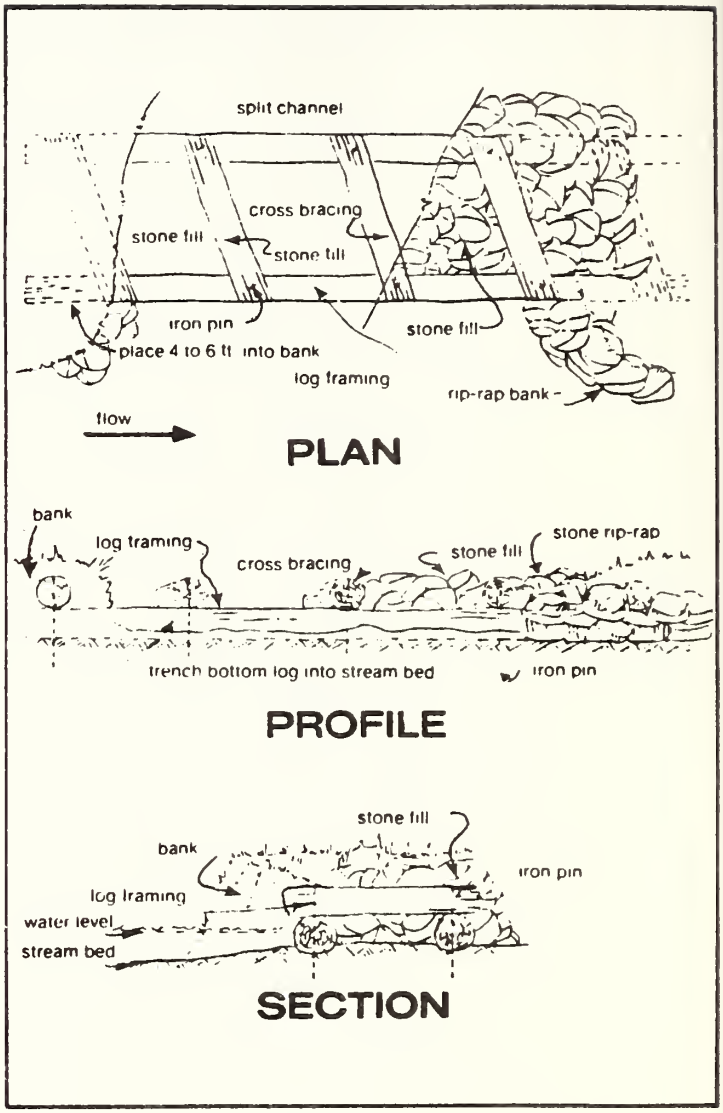
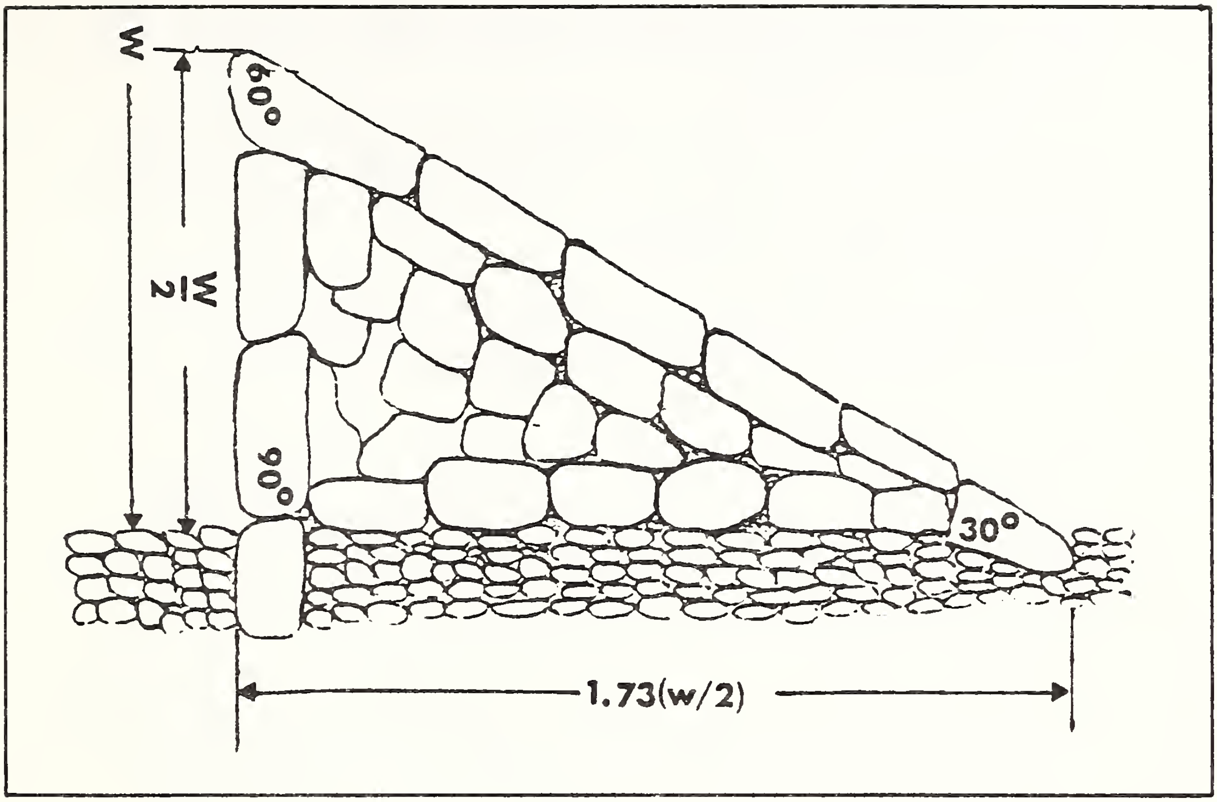
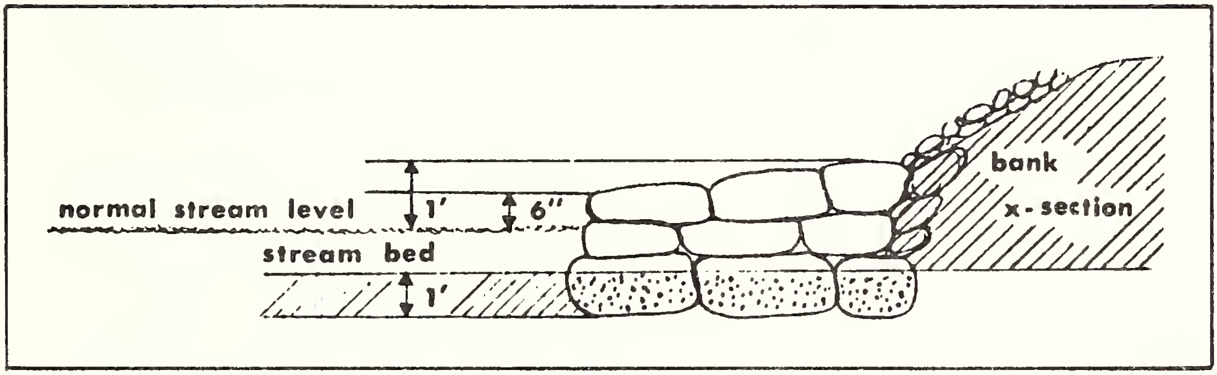


Figure 1-13. Channel block.

Source: Miller and Tibbott 1980



Top view



Upstream view

Figure 1-14. Single-wing rock deflector.

Source: British Columbia Ministry of Environment 1980 (Top view)
North Carolina Division of Inland Fisheries 1971 (Upstream view)

some soft-bottom streams, sheet piling has proved effective (see Figure 1-16); but it provides no cover for fish, deteriorates rapidly, and is unsightly.

Where used to protect banks, a series of short deflectors or one long deflector may be used. For extremely long eroding bank areas, a retaining wall is most effective. This is particularly true at sites with unstable, sandy banks.

In many cases, where deflectors are used to stop erosion, long-term improvement depends on establishing protective vegetation. In such instances, deflectors serve mainly to protect the eroding bank long enough for vegetation to become permanent.

In small streams, it is sometimes desirable to cut off side channels to concentrate the flow in a single channel as shown in Figure 1-14. This aids in keeping down water temperatures, increasing small flows, or, in some cases, directing the flow to a better channel.

Opposing deflectors are sometimes used effectively to scour pools. Constricting the channel increases the velocity between structures, thus increasing the scouring action. As a general rule, opposing structures should not constrict the channel more than half the channel width. This type of improvement should be installed in straight sections of channels.

The following general rules should be considered when installing a deflector (British Columbia Ministry of Environment 1980):

(1) Avoid installations in unstable floodplain or braided channel reaches of stream. In these areas, structures may rapidly become ineffective or may add to existing instability.

(2) Locate the deflector well below the riffle to avoid impounding water upstream.

(3) To improve performance, deflectors should form an angle no greater than 30 to 45 degrees with the stream bank. Experience indicates that this improves their performance. The appropriate angle and length of wing will be specific to each site and should generally conform to the natural meander sequence of the stream. It is better to gently direct current than to abruptly force it with a large directional change.

(4) Boulders or rock-filled gabions are best suited for construction of wing deflectors. When individual rocks are used, the size of individual boulders will depend on the characteristics of the stream. Generally, rocks for wing deflector construction should not be less than 2 feet in diameter.

(5) Where the wing deflector connects to the river bank, the point of connection must be protected by riprap or gabion to above the flood level to prevent the river from washing around the end of the deflector. Similarly, the bank opposite the deflector must also be protected to eliminate erosion that could be harmful to fish habitat or streamside property.

(6) To minimize scouring of the foundations of wing deflectors constructed with large rock, always use a minimum of two rows of rock with the joints staggered. The second row should be set into the bottom of the river with the top slightly lower than the first row of rock, and the deflector should be triangular in shape.

(7) If possible, secure cable log cover (preferably cedar) to the revetment on the opposite bank. To provide additional cover, accelerate scouring of the pool or run.

(8) Where the streambottom is composed of coarse material, pre-excavation of the intended pool or run may be required to speed up the natural erosion process and to ensure development of suitable habitat.

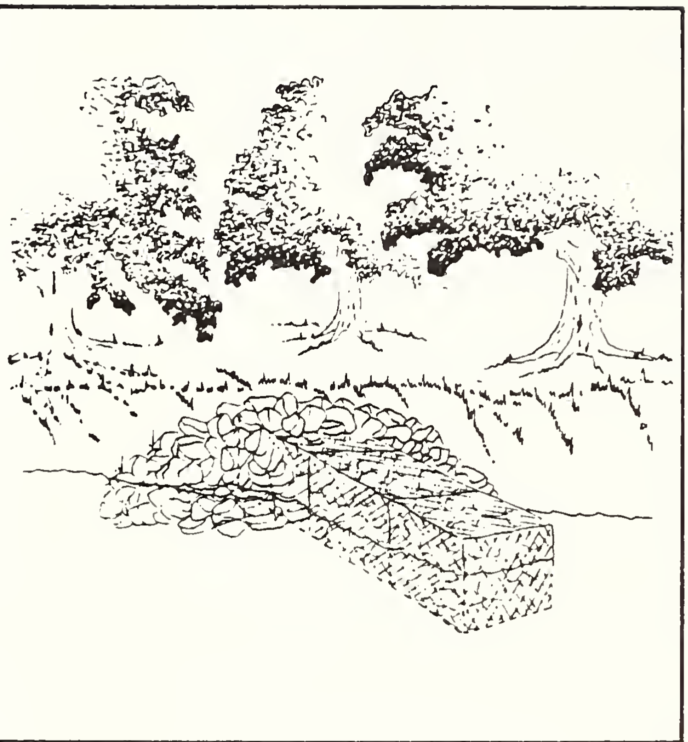
(9) The height of the wing deflector should be set so that at peak flows it is sufficiently submerged to pass logs and debris. If the deflector is set too high, severe bank and channel erosion could result.

Gabion Deflectors

Gabion baskets are very effective in constructing deflectors, particularly where rockfill is available. However, structures may create large pools that cause the structures to settle or even roll into the pool. Because of the flexibility of the basket, though, the structure often continues to function but with reduced efficiency. Careful placement and construction is necessary.

Procedures for constructing gabion deflectors for bank protection are similar to those described for gabion dams. The angle and distance between structures for high waterflows should be determined. The greater the velocity, the smaller the angle of deflection, and, similarly, the smaller the radius of the channel curve, the closer the location of structures.

Opposing gabion deflectors should be limited to straight channels (Figure 1-15). As with all structures, each should be keyed into the bank at a safe distance to prevent end-cutting.



Gabion deflectors consist of stone-filled wire baskets tied together and embedded in the streambed for about half the height of the baskets The deflector extends at an angle of 30°-40° from the downstream bank. Riprap is placed around the gabion where it intersects the bank.

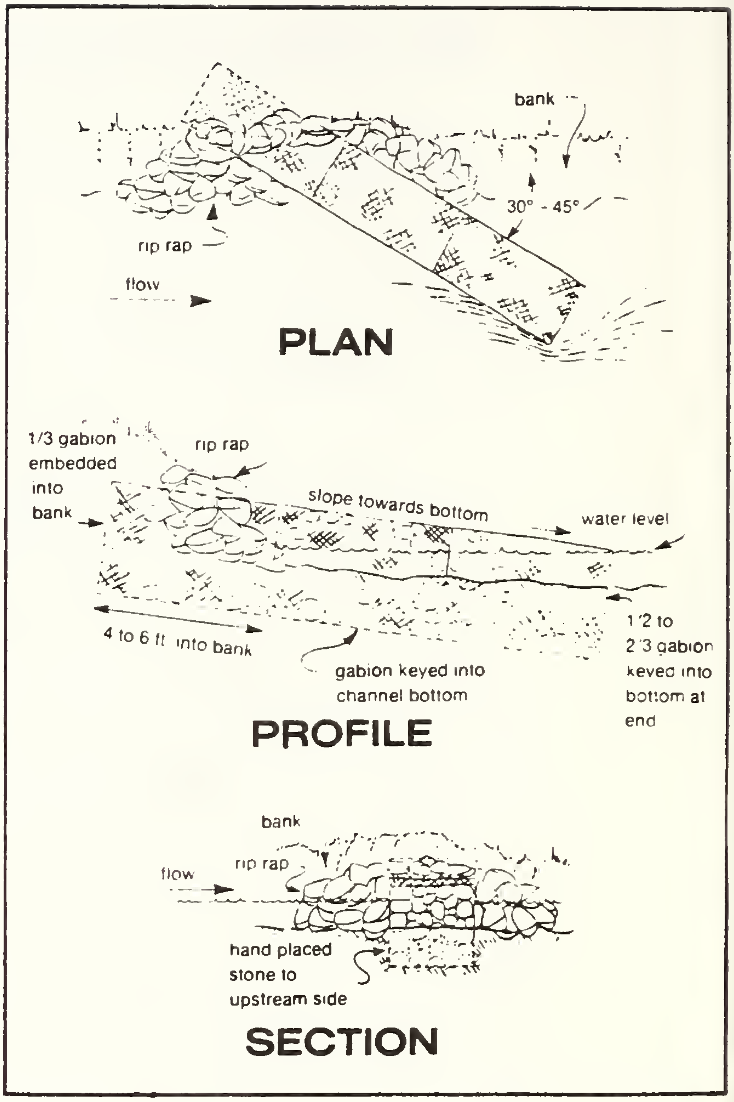


Figure 1-15. Gabion deflector.

Source: Miller and Tibbott 1980

Sheet Piling Deflectors

For streams with a sandy bottom, the use of sheet piling in the construction of deflectors is effective (Figure 1-16). Sheet piling is best installed with a jet outfit that includes, at a minimum, small portable centrifugal pumps with a capacity ranging from 3,500 to 5,500 gallons per hour; a two-cycle, air-cooled gasoline motor of about 1.5 horsepower; a jet nozzle; and a hose conforming to the inlet and outlet sizes of the pump.

Sheeting of 1-1/4-inch lumber, 6 to 8 inches wide, is satisfactory for most conditions. Lumber should be tongue and groove, preferably with a 1/2-inch tongue and loose-fitting groove.

The first step in constructing a sheet piling deflector is to install a guide called a waler by jetting in several posts at the desired angle to the streambank and spiking the waler to the upstream side. It is best to place the waler below the waterline and extend it a distance into an excavation in the bank.

Sheet piling should be started at the outer end of the waler with construction progressing toward the bank. The bottom end of each board should be sawed off at approximately a 60-degree angle so that in driving it will be forced against the board already in place. Boards may be put in place by holding the jet at the base of the piling and pushing them into place by hand or tapping lightly with a maul. Each board should be nailed to the waler as soon as it is put down. Piling should be extended well into the bank and any sod or dirt removed in trenching for the waler should be replaced. Tops of piling should be trimmed so that they extend only a few inches above the water at the outer end and the height should be increased gradually to the bank end. If desired, a log cap may be added to give a more natural appearance.

Unfortunately, the use of sheet piling results in rapid wood deterioration from exposure to air, an artificial appearance, and little or no cover for fish.

Trash-Catcher Deflectors

An inexpensive deflector can be constructed similarly to trash-catcher dam using meshed wire and posts. The end of the structure protruding into the stream is anchored by driving three posts close together. In addition, these anchor posts are driven 3 to 4 feet into the streambed, depending on the size of bottom materials and probability of scouring.

Rock Deflectors

Rock deflectors, the simplest type of deflectors, are often used in place of other types of deflectors to create pools or irregular bank patterns. They should be built in a roughly triangular shape,

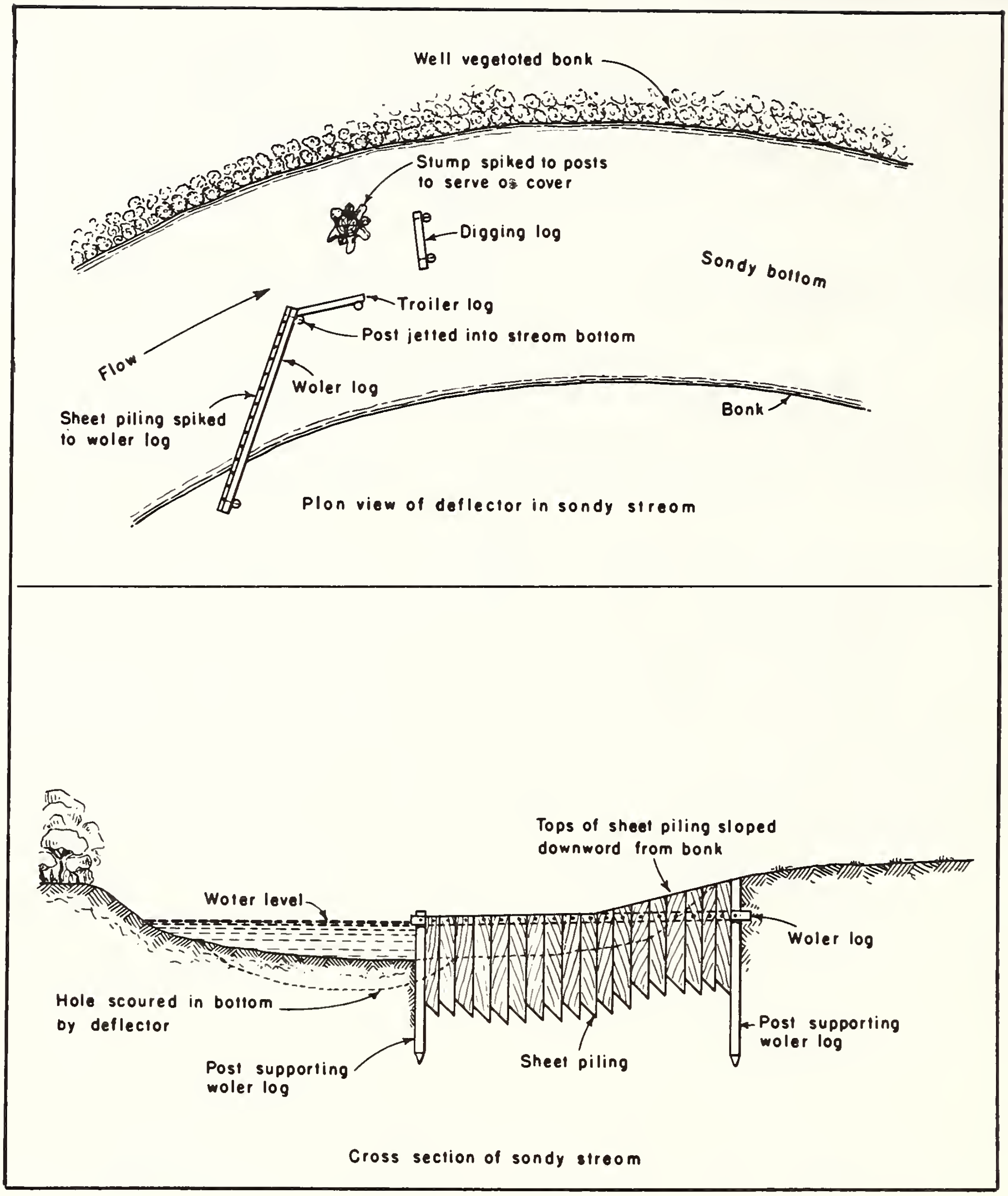


Figure 1-16. Sheet piling deflector.

rather than in a peninsular shape, and solidly filled with rocks and soil (Figure 1-17) to protect the streambed and banks against damage by high water (White and Bryunildson 1967). To stabilize a rock deflector, its outline must be made of rocks large enough that high water is not apt to move them. The center can be smaller rocks, but they must be carefully placed so they are not easily washed away (Pennsylvania Fish Commission 1974).

Rock deflectors have a natural appearance, provide hiding places for fish, and serve as a site for invertebrate production.

Log Frame Deflectors

Log frame deflectors consist of a triangular log framework filled with stone. The logs should extend at least 6 feet into the stream bank and be well anchored to the stream bottom with 3- to 4-foot pieces of 1/2- to 5/8-inch reinforcing rod (Pennsylvania Fish Commission 1974) (Figure 1-18). Stones should be hand placed as tightly as possible within the framework to prevent the deflector from being washed out by high water.

Tip Deflectors

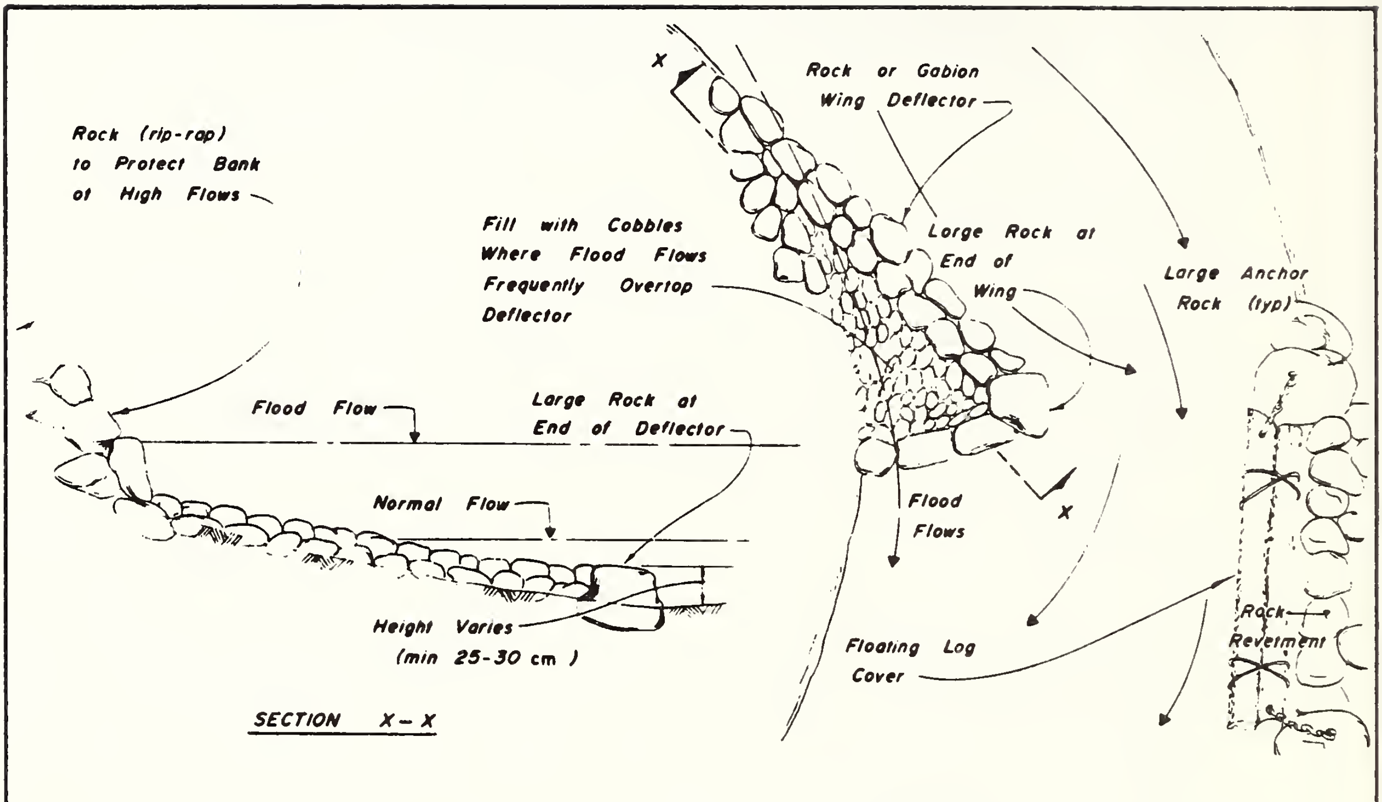
Tip deflectors are a specialized form of the log frame deflector (Figure 1-19). Instead of the deflector being entirely filled with stone, the instream tip consists of a layer of 2-inch oak boards suspended above the stream bottom (Miller 1980). The tip should be underwater during normal flow. The current flowing beneath this tip scours out a pool that, with the overhead cover of the boards, provides fish cover.

Tree Retards

Tree retards protect the streambank by slowing the current and accumulating debris. The submerged branches provide fish cover. Tree retards are constructed by installing trees in a horizontal position, transverse to the stream flow. They are anchored with stone fill onshore and with cables attached to concrete anchors or large rocks both onshore and in the water (Figure 1-20). This erosion control method is aesthetically appealing because it simulates the natural appearance of undercut trees falling into the stream (Selnick et al. 1982). The trees need to be replaced every few years.

Timber Cribs

Timber cribs divert flow from eroding banks. Timber or railway ties are placed perpendicular to the shore, one on top of another (Figure 1-21). Timber cribs require maintenance, particularly after high water and storms, but are easily constructed and repaired (Schnick et al. 1982). Timber cribs have been used both on small streams and, on a limited basis, in large rivers of the Western United States (Keown et al. 1977).



Typical wing deflector constructed from rock. The current will scour a deeper pool on the opposite bank. Two logs lashed together with cable provide floating cover. Anchor cable must be located to avoid snagging debris.

Figure 1-17. Rock deflector.

Source: British Columbia Ministry of Environment 1980

A log frame deflector serves the same functions as a stone deflector and may be used in similar situations. Log deflectors should be kept low to allow flood waters to flow over them.

Deflectors are basically 30°-60°-90° triangles with the long side abutting the stream bank, the short side facing downstream. A log frame is constructed and buried in the bank. The logs need to be pinned to the streambed and to each other with metal rods or other suitable holding device. The frame is then filled with stone, and stone is placed on the outer edge of the logs where they intersect the bank in order to prevent scour. The upstream log overlaps the downstream log.

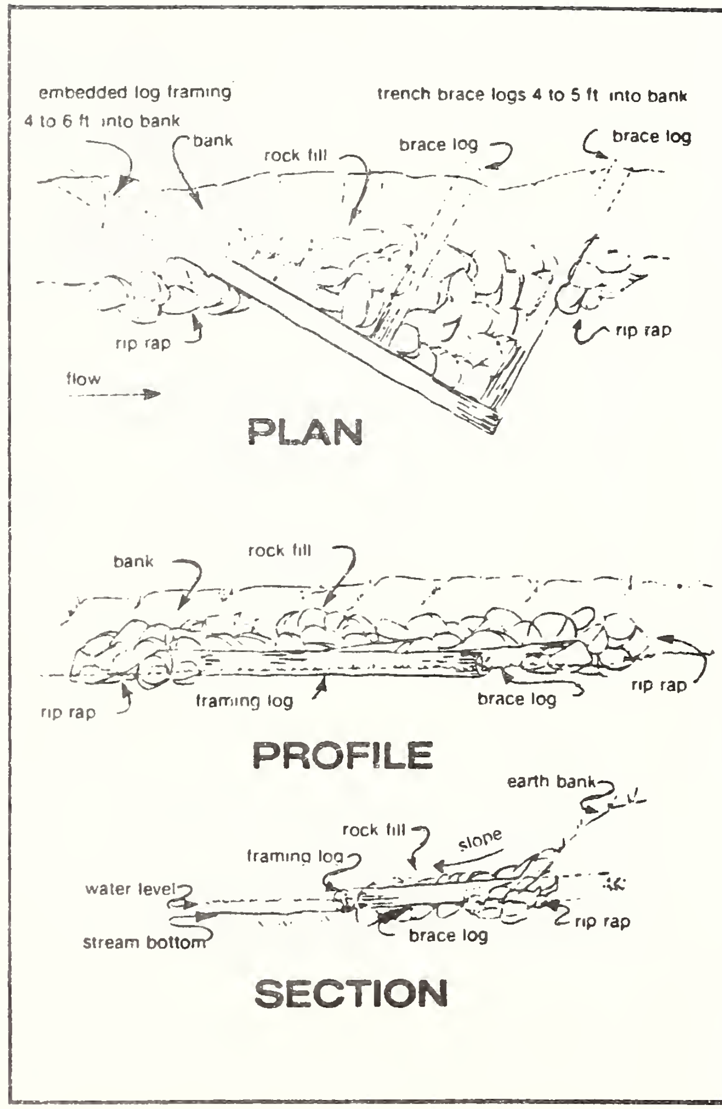
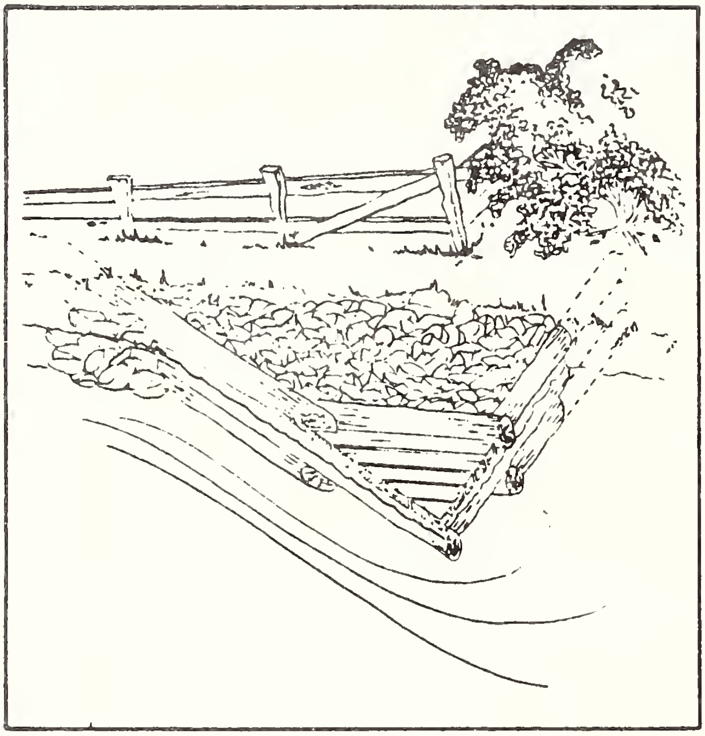


Figure 1-18. Log frame deflector.

Source: Miller and Tibbott 1980



Tip deflectors are similar to log deflectors but are typically three logs high, each log being 12" or less in diameter. Logs are buried in the stream bank and pinned to each other and the streambed. A 2" thick timber deck is constructed at the tip of the deflector providing cover for fish. The remaining portion of the frame is then filled with stone sloping upwards to meet the bank. To prevent scour, stone will be placed on the outer edge of the frame where it intersects the bank.

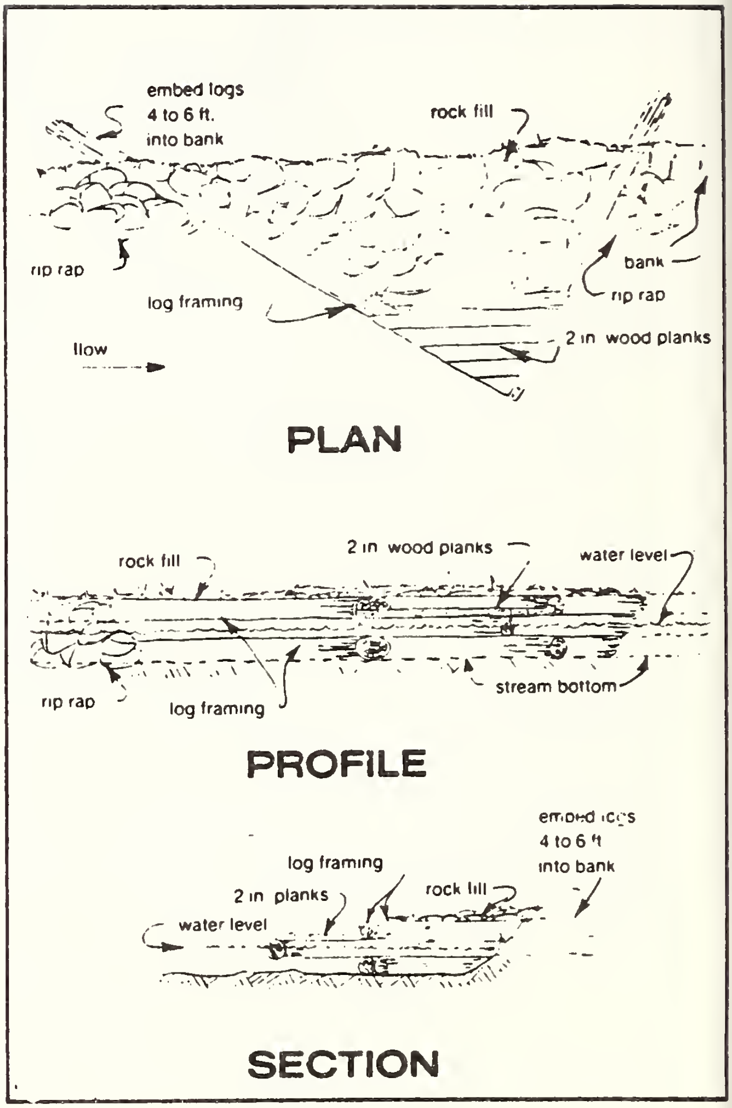


Figure 1-19. Tip deflector.

Source: Miller and Tibbott 1980

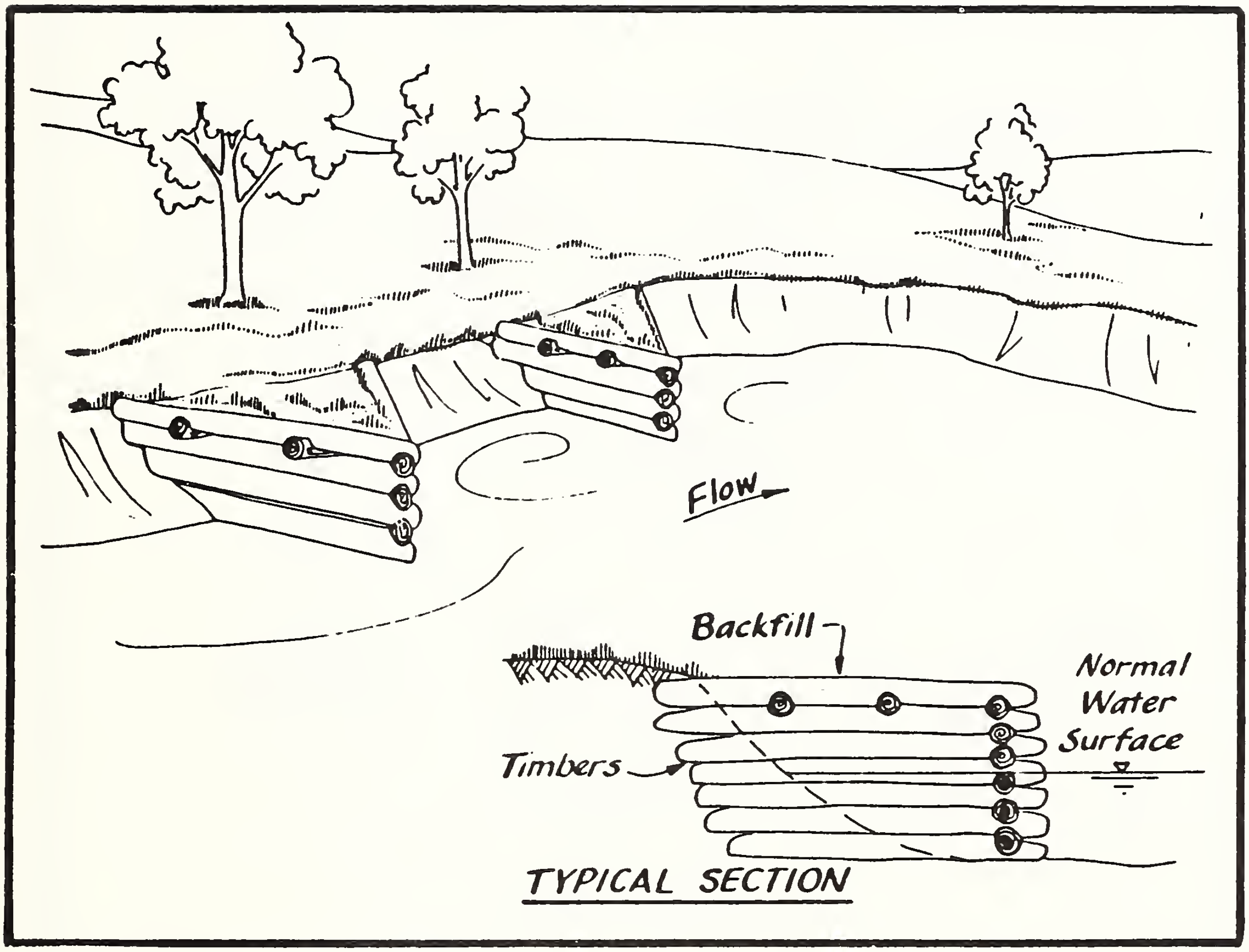


Figure 1-20. Tree retards.

Source: U.S. Army Corps of Engineers, Rock Island District 1980

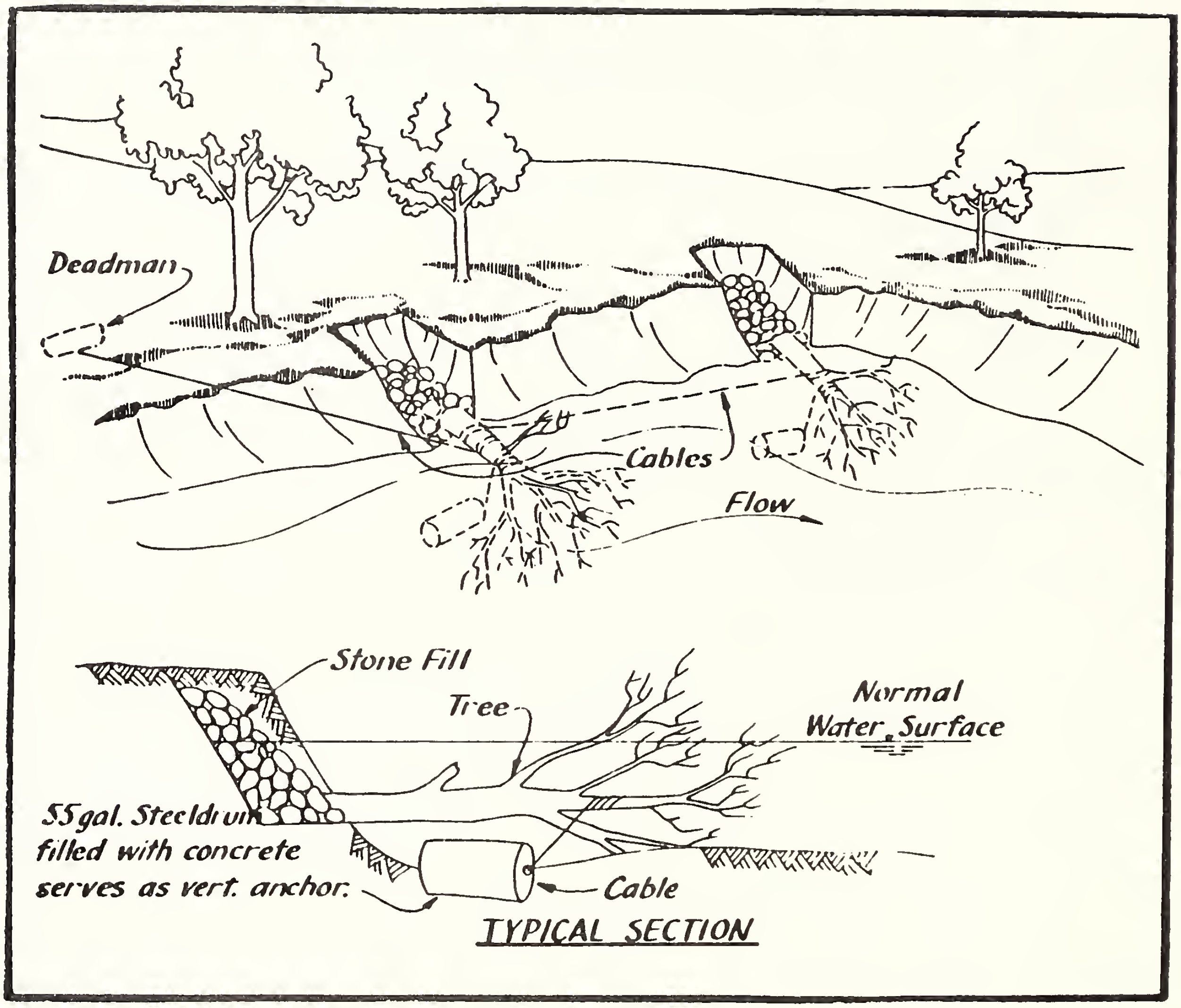


Figure 1-21. Timber cribs.

Source: U.S. Army Corps of Engineers, Rock Island District 1980

Timber cribs should be used on wide streams, both small and large, with volumes exceeding 100 ft^3/s. On large streams and high-gradient streams, materials should exceed 300 to 400 pounds per rock to withstand flood velocities. Use rock deflectors when sufficient supplies of large rock and heavy equipment are available to haul and place the rock.

Cabled Tree Deflectors

Cabled tree deflectors consist of both large and small brushy trees that serve as partial deflectors and also as fish cover. Cabled trees are secured parallel to the bank with the butt of the tree pointing upstream. The more limbs a tree has, the greater the amount of deflection. When possible, cables should be buried to prevent fishermen and animals from tripping over them. Well-rooted stumps or deadman anchors often are used (Figure 1-22).

Cover Devices

Brush and shrubs reaching over and into water and brush, branches, and dead trees that fall into the water can provide natural, stable cover. Although efforts should be made to preserve the beneficial aspects of this cover, excess cover may reduce fish production. Trees, large branches, root wads, boulders, submerged logs, and other structures may be anchored along or against the stream to provide cover. Following are general guidelines for the construction and installation of cover devices in streams (British Columbia Ministry of Environment 1980):

(1) Cover should be incorporated with other stream enhancement devices such as deflector wings, overhangs, and rock clusters.

(2) Trees, limbs, brush, and root wads should be anchored in the stream in a manner that avoids damming.

(3) When whole trees are used for cover, the fine branches should trail downstream with the butt section anchored to the streambank.

(4) The tree butts should be anchored above high water or in a manner that will not snag floating debris.

(5) Floating logs, trees, brush, and large branches anchored along the streambank should be parallel to the stream flow.

(6) Floating log cover should be placed adjacent to steep banks to avoid logs hanging up on the bank during low-water periods.

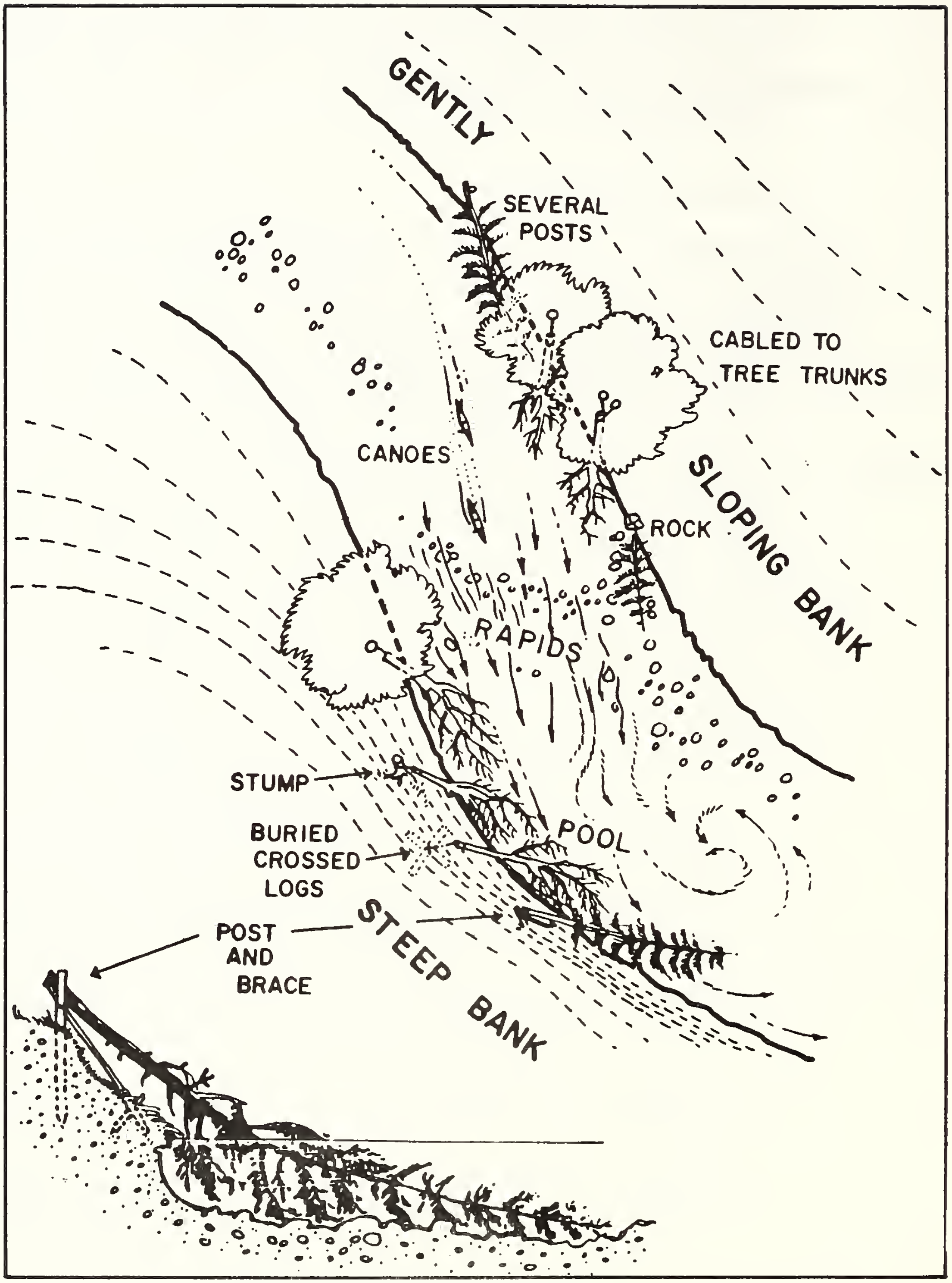


Figure 1-22. Cabled tree deflectors.

Source: British Columbia Ministry of Environment 1980

(7) Because decay and physical damage limit the life of floating logs, branches, and cut trees, these cover devices should be regularly replaced and maintained. Fast-rotting species such as alder should be avoided. Cedar is a preferred species.

(8) Streamside trees should be used only with the permission of the property owner involved.

Wisconsin Bank Cover

The Wisconsin bank cover-current deflector is an artificial, overhanging ledge placed at the outside of bends where current sweeps along the bank. It makes an ideal hiding place for fish, and it stabilizes the bank. Following are construction steps for this cover (see Figure 1-23): (1) jet in pilings, (2) lay stringers, (3) spike down longitudinal 2-inch oak planking, (4) revet rock behind the overhang, (5) cover with rock, (6) cover finished device with soil and sod (White and Bryunildson 1967). The longitudinal oak planking should be underwater during normal stream flow. The Wisconsin bank cover-current deflector has been successfully used on streams up to 50 feet wide in the Midwest.

The Wisconsin Department of Natural Resources has substituted sand bags for rock in areas where rock is scarce. Polypropylene bags are filled with sand or silt from the streambed resulting in a substantial savings in construction costs when working in an inaccessible area or an area where rock is not available.

The use of prefabricated platforms of wood measuring approximately 8 by 6 feet wide (Figure 1-24) eliminates the need for supporting pilings and onsite construction of underwater platforms of wood planking (Hunt 1980). About 30 inches of the width dimension is solidly decked with 2-inch planking. These prefabricated platforms are designed for use on 30- to 90-foot-wide streams with rubble or sand substrates. The cover is installed by mechanically digging a trench in the stream bottom to create a deeper channel and then leveling the bottom on the near-bank side of the trench, so that the prefabricated sections can be laid on the bottom and cantilevered over the trench. The 30-inch deck constitutes the portion overhanging the trench. Rock and dirt are applied to the middle, rear portion of each platform to counterbalance it in place. Material from the dug trench or channel should be used as fill on top of the platforms. Larger rocks should be positioned by hand along the front edge of the platform on the face of the new bank as the platform is being covered by a backhoe (Johnson 1982). A partial log along the front edge of the platform prevents the rocks from tipping off. On sand substrate streams, a 12-inch vertical wall should be added to the platform at the back of the decking to prevent sloughing of material back into the channel from the backside.

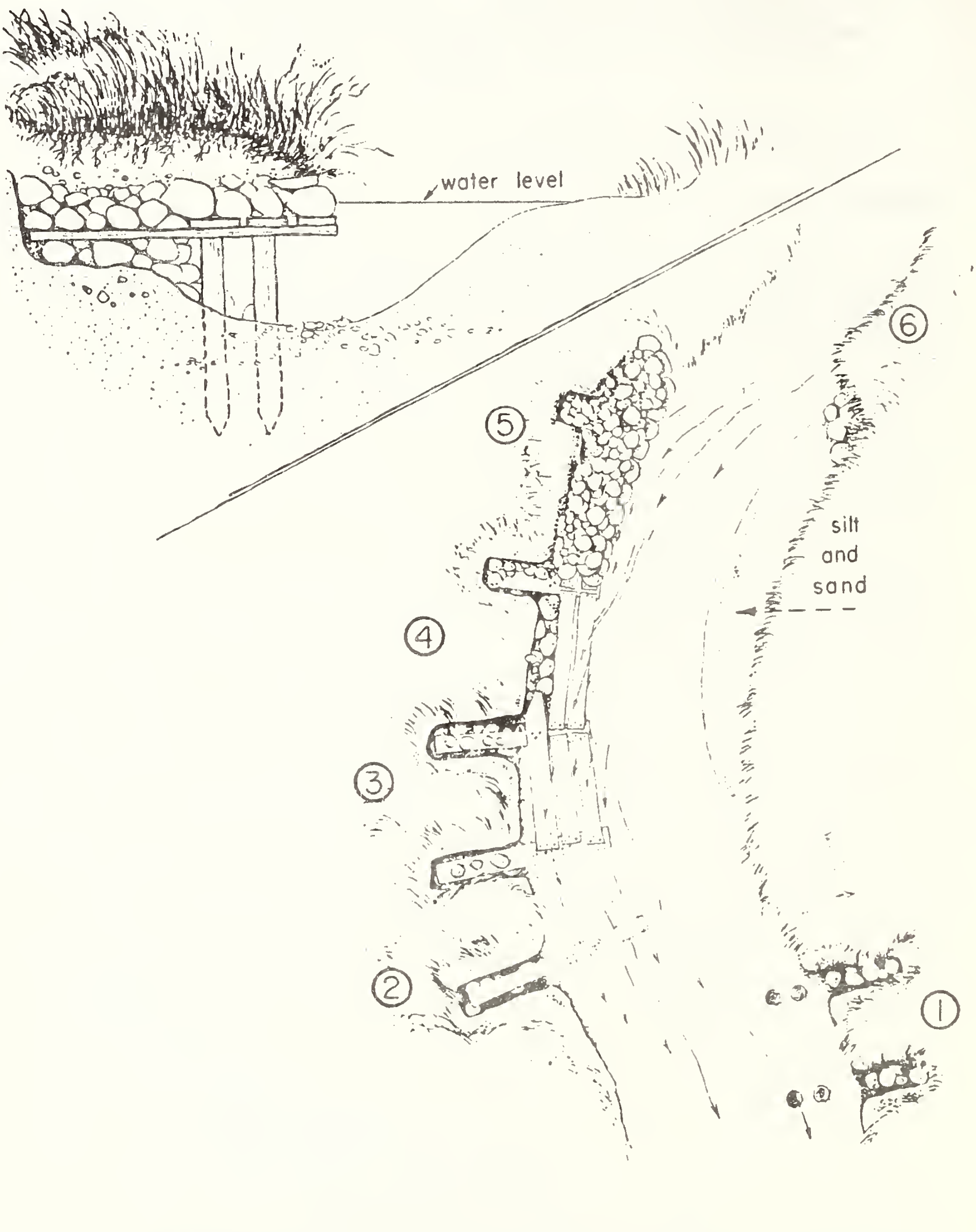


Figure 1-23. Wisconsin bank cover-current deflector.

Source: White and Bryunildson 1967

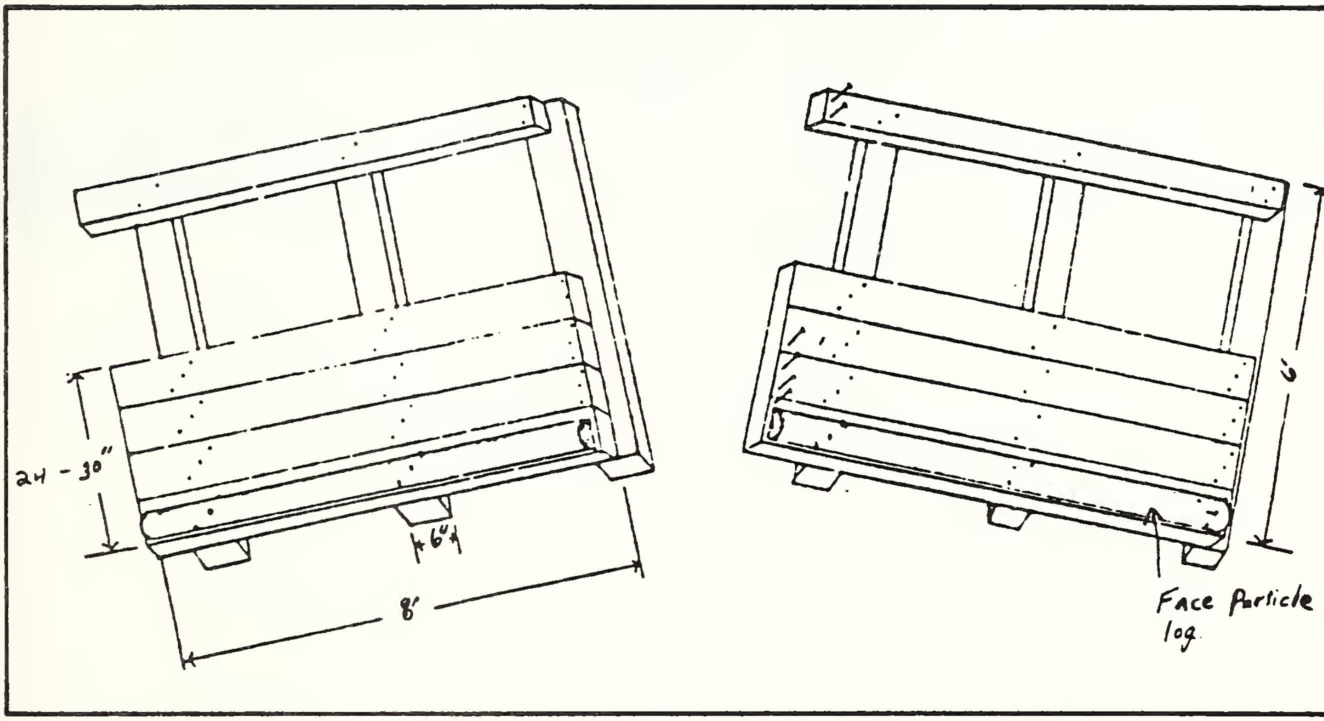


Figure 1-24. Prefabricated wooden platform used as an underwater substructure for bank cover-current deflector devices.

Source: Johnson 1982

Mud Sill

A mud sill is a type of cribbing. Where bank erosion on a curve is a problem, a mud sill provides protection against erosion and overhead cover for fish (Figure 1-25). Sills should be placed perpendicular to the bank. A staggered formation should be used to give better waterflow under the floored section. The sills should extend 6 feet into the bank. After the sills are pinned into the bottom with 48- to 60-inch reinforcement rods, they should be covered with 2-inch oak planks nailed to the sills. A face log or logs should be placed along the streamedge of the flooring and pinned to the sills. The entire structure should be covered with rock to bank height, then with soil and seed. A short deflector and heavy riprap should be tied into the upstream end to prevent the stream from cutting behind the mud sill (Miller 1980).

Logjams

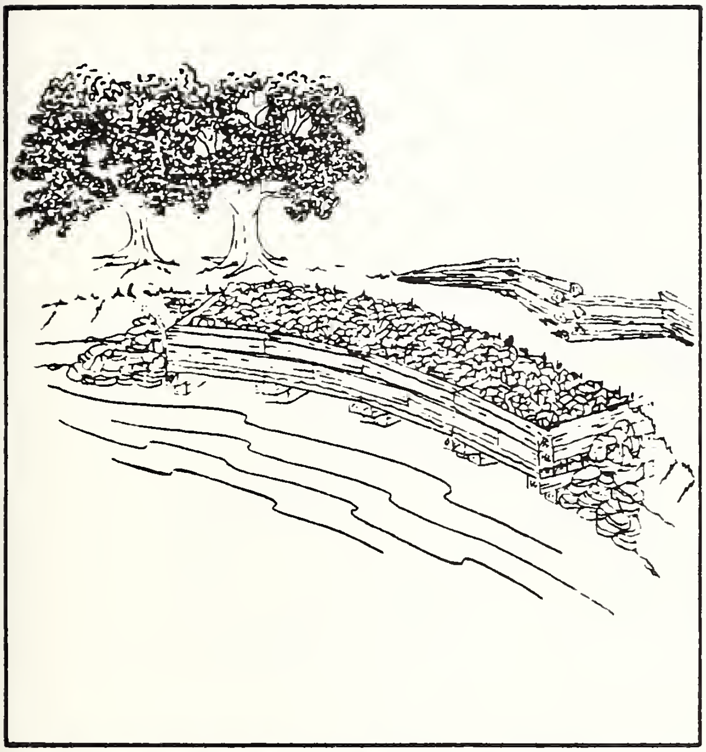
Logjams are modified bank covers and some of the most common and versatile stream improvement devices used in Michigan. While their main function is to provide pools and escape cover, slight modifications provide bank stabilization.

Logjams should be placed along one bank, usually on the outside of a bend or on straight stretches where the water is of sufficient depth (1 to 4 feet) (Figure 1-26). The structure can vary; however, maximum width should not exceed one-half the channel width.

Logjams should be set at normal midsummer water levels, protruding approximately 1 foot above the water. The structure should be slightly higher along the edge of the streambank to protect against erosion deriving from high water. Both ends of the structure should be tapered into shore to eliminate collection of debris. The suitability of the structures for fishing can be maximized by setting the face of the structure along the edge of the current flow, but logs or capping material should not extend out beyond the outer edge of the structure.

The logjam should be anchored firmly to the bottom by jetting in several posts throughout the structure. Materials should be fastened to the anchor posts or to the other materials with 4- to 12-inch spikes. Green logs should be used as an underlay, and then stumps, snags, or old logs should be used on top. Clumps of sod should be added to the top of the structure and tops of posts covered with pieces of old stumps. This treatment gives the structure strength and stability as well as a natural appearance.

For bank stabilization, more material is used along the bank to form a dense barrier to the current flow within the structure. A properly built structure will be effective even during high water.



Where there is serious erosion which necessitates reestablishment of the shoreline, a mud sill, a structure similar to a channel block, may be used. Materials such as old railroad ties are very good for this purpose. To provide shelter for the trout, as well as to control erosion, the cribbing may be used in conjunction with a floored mud sill as pictured here. Each sill consists of railroad ties wired or pinned together. The sills are floored with other ties as far back into the bank as possible. Normal water level should be at or near the top of the flooring. A sufficient quantity of rocks is placed on top of the flooring to restore the eroded area and prevent the large amount of wood from being buoyant.

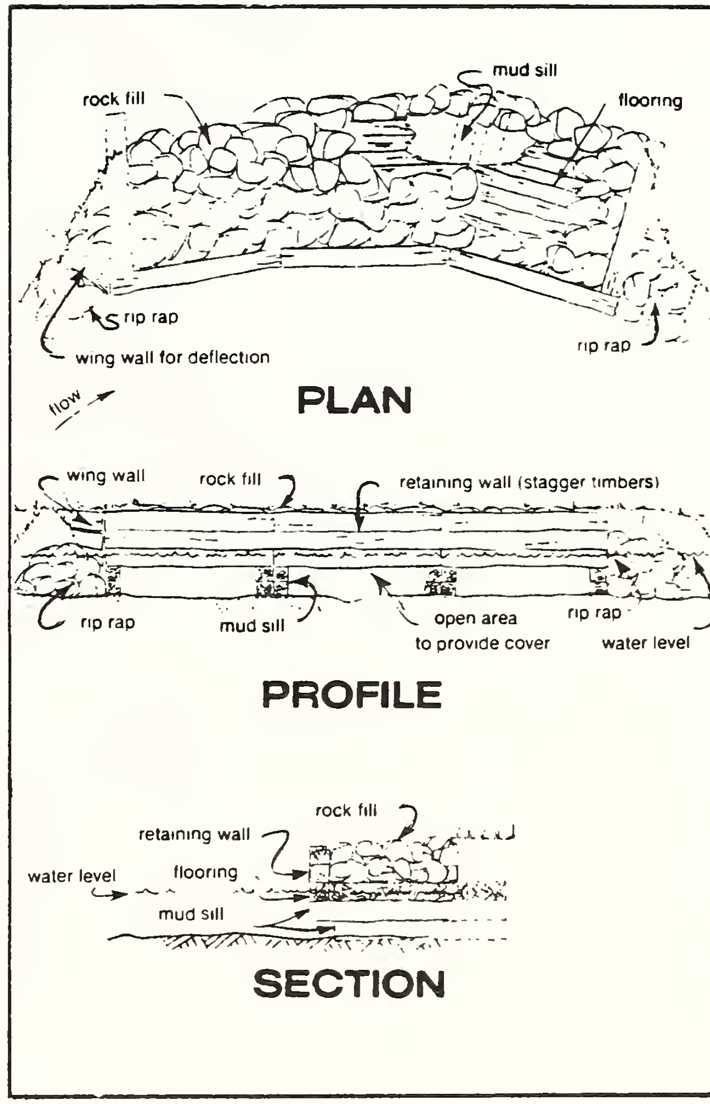


Figure 1-25. Mud sill.

Source: Miller and Tibbott 1980

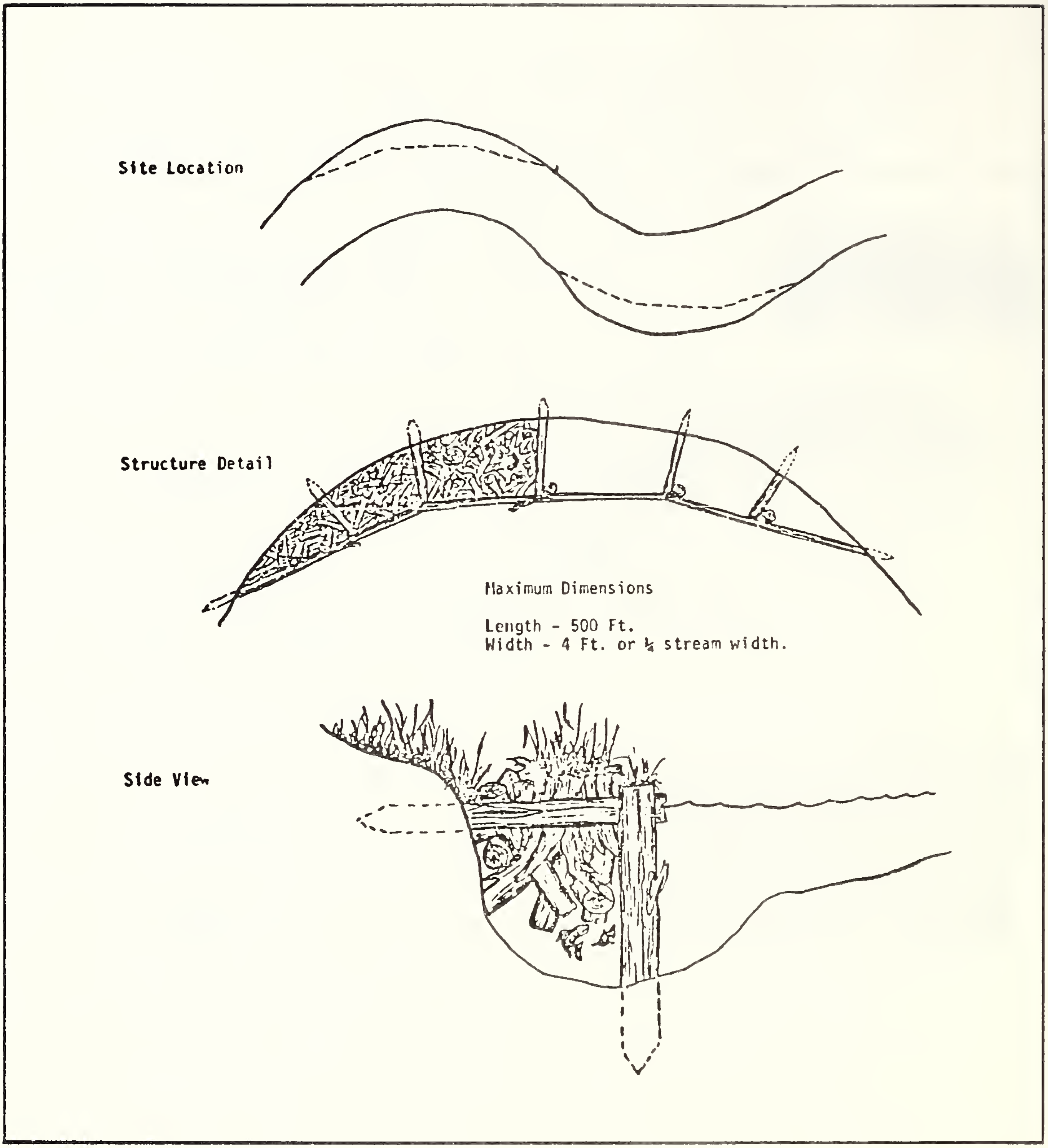


Figure 1-26. Logjams.

Source: Michigan Dept of Natural Resources

Cover Logs

Cabled cover logs can be attached to rock wing deflectors along bank revetment or anchored mid-channel. Log cover, cabled securely and tightly to bank revetment, will tend to increase fish-carrying capacity (Ward and Slaney 1980). The potential for snagging floating debris can be minimized by ensuring that no log ends project during high-water levels. Cover logs can be any shape, length, or size, but best results are obtained with large (over 1-1/2 feet in diameter), crooked cull trees providing a nonuniform surface and resulting in maximum turbulence along the edge of the log (Seehorn 1982). Leaving stubs of limbs several inches long creates additional turbulence and spot scouring. Large stumps also provide excellent cover. In most cases, cover logs should be pinned into stream bottoms or banks with 4- to 6-foot long, 3/4-inch reinforcing rod. Cover logs are suitable for use in any size stream, and they are inexpensive, present a natural appearance, and require less maintenance than do most other structures (Seehorn 1982).

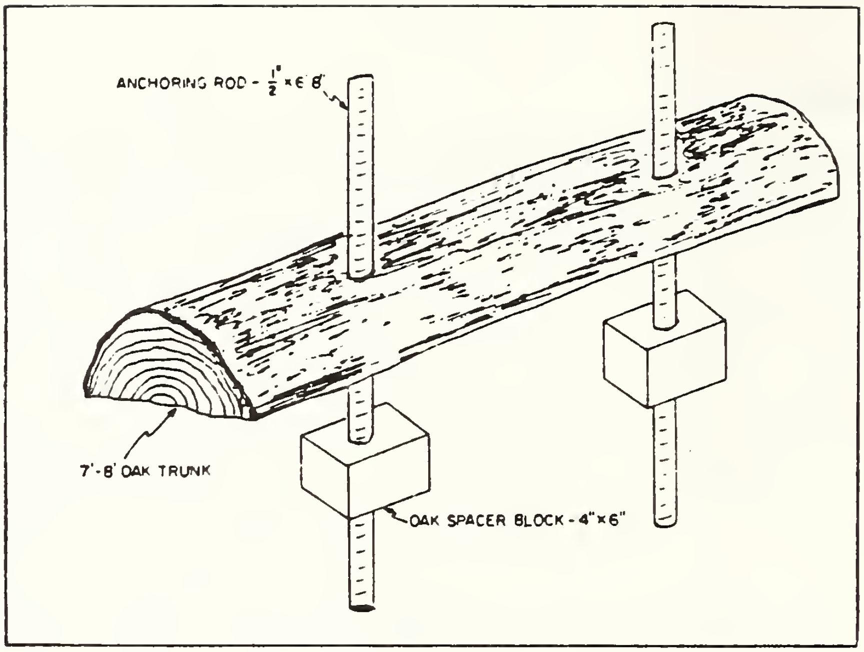
Half-Logs

Half-logs were designed specifically to reduce the effect of inadequate hiding cover as a limiting factor on trout abundance, especially Age II (1 inch) and older trout (Hunt 1978). Half-logs are simple in design and easy to install. A single structure consists of one-half of a log approximately 6 to 8 feet long and is 6 to 12 inches in diameter (Figure 1-27). A hole is drilled through each log at each end to accommodate entry of 1/2-inch-diameter reinforcing rods.

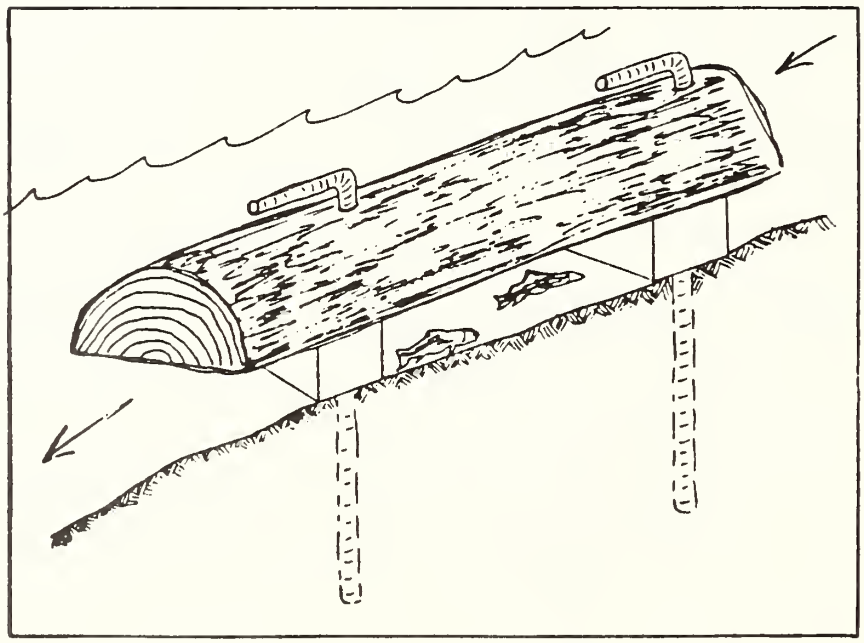
Drilled wooden spacer blocks are slipped on the rods from the flat side of the log. The spacers hold the log off the stream bottom so that trout can hide beneath the log. Installation consists of positioning the log nearly parallel to the flow, and preferably, over a substrate of gravel or rubble in water depths sufficient to submerge the log and spacers. Anchoring rods are driven into the bottom to anchor the log. The upper 6 to 8 inches of each rod are bent downstream along the upper face of the log to complete the installation (Figure 1-27). Care must be taken to use them only where the current is sufficient to keep them from silting in. A third spacer block or cleat may be nailed midway to the bottom of longer half-logs for separate compartments.

Brush Bundles

Brush submerged in the stream current along the bank provides the best general hiding cover for trout of all sizes (White and Bryunildson 1967). Brush bundles can be used to narrow and deepen small streams. When butted into a bank in shallow water and staked down, they can be completely covered with silt in 1 to 3 years. This is a good technique to use in older, damaged streams. Along



Component parts of a half-log structure used to provide hiding cover for trout.



A half-log structure after installation.

Figure 1-27. Half-logs.

Source: Hunt 1982

small streams, brush is cut off the banks and secured carefully along the edges of the stream in a way that will not dam the flow. Tree tops also can be used; and in large streams, whole trees. Maintenance of brush structures requires repeated work because they deteriorate in 2 to 5 years.

Random Boulder Placement

Well-placed large boulders are effective in producing pools, cover, and resting areas for fish. Visually, they appear natural and pleasing to the eye. Depending on availability, the placement cost is relatively inexpensive. Boulder placement has been found to increase the numbers and biomass of trout, salmon, and other fish. Rock grouping installations require minimal maintenance because minor movements of individual rocks do not seriously reduce the installation's effectiveness.

In project planning, the following points should be considered:

(1) Boulder placement is most effective in wide, shallow, and high-velocity stream channels. In addition, channels should be characterized by large gravel or rubble bottom types. The substrate on which rocks are placed must be stable enough to prevent large rocks from being buried by undercutting (Reeves and Roelofs 1982).

(2) Avoid boulder placement in narrow channels with unstable banks where they could cause erosion problems. Normally, boulder placement is not necessary when the pool-riffle ratio exceeds 20 percent pools.

(3) Use irregularly shaped large boulders 2/3 cubic yard or larger. Large shot rock blasted from quarries is excellent because it has sharp edges that resist rolling in the current. Place boulders using helicopters, large-sized end loaders, or crawler tractors. Streambank damage is reduced by careful choice of access points.

(4) Place boulders in the channel to imitate natural occurrence (Figure 1-28). Oblong boulders placed with the long axis at right angles to the streambank are most effective. Take care in boulder placement to avoid diverting the current into soft or unstable banks. Place all boulders so that they will be operational in low-water periods.

(5) As a rule of thumb, the maximum number of boulders placed should not exceed one per 300 square feet of channel. Boulders may be placed individually or in groupings (Figure 1-28). Ward and Slaney (1980) recommend triangular groupings of 3 to 5 boulders using rock no smaller than 2 feet in diameter. However, a suitable spacing (6 to 9 feet) must be maintained

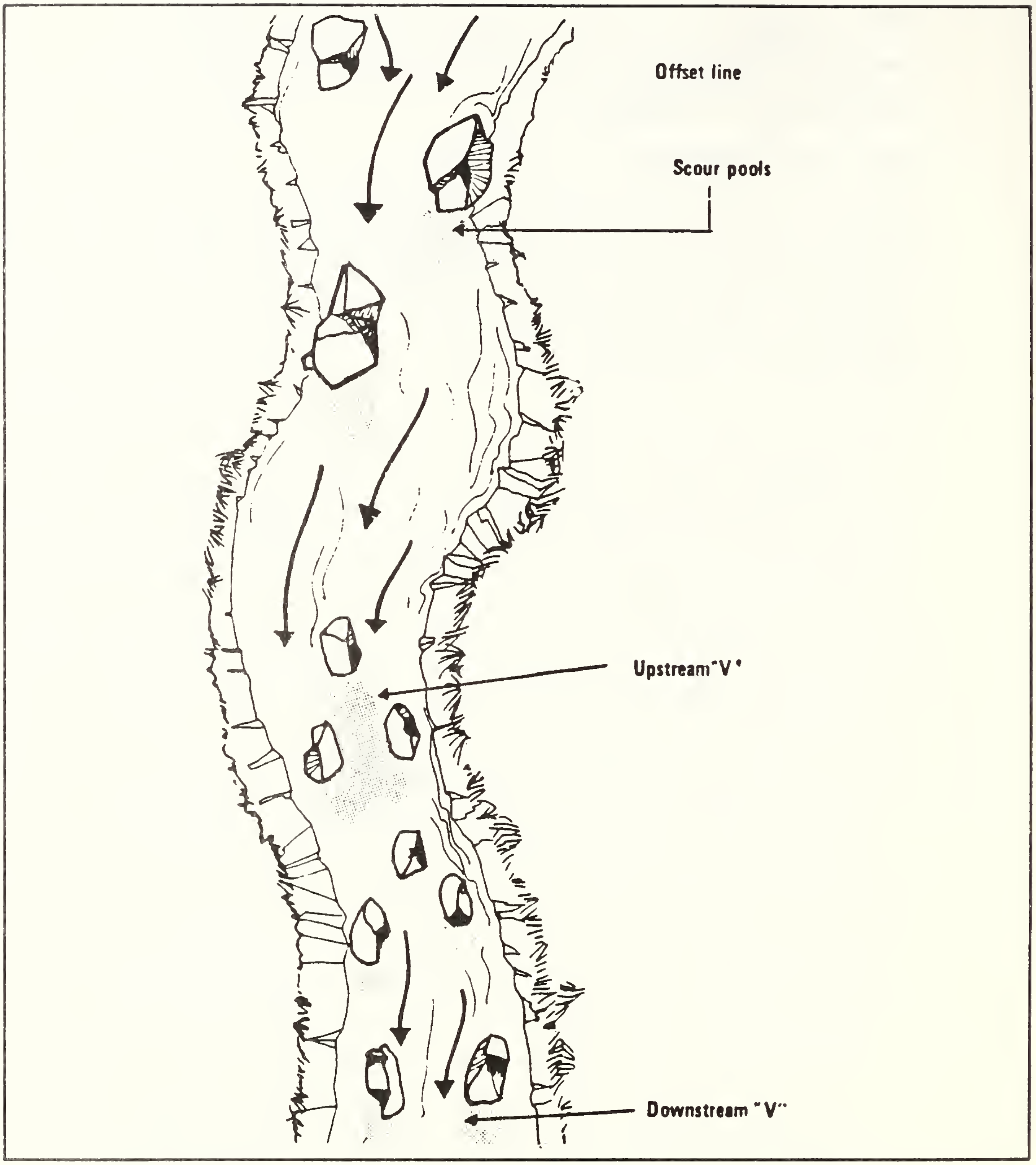


Figure 1-28. Random boulder placement.

between the individual rocks to avoid accumulating debris and traploading bedload material (British Columbia Ministry of Environment 1980).

Spawning Habitat Egg-laying fish deposit their eggs in several distinctly different manners. Most species deposit their eggs above the stream bottom, but others, such as salmon and trout, bury their eggs below the bottom. Because of very specific incubation requirements, propagation problems are most likely to occur with the latter group.

For those species that bury their eggs, successful propagation is dependent upon maintenance of a sufficient flow of water and available oxygen through the gravel during incubation, hatching, and emergence periods. Streams sustaining large wild populations of smallmouth bass, trout, and salmon have large amounts of streambed gravel. Individual species prefer gravel of varying sizes. As a general rule, large fish choose spawning locations of higher velocity and coarser gravel than smaller fish. The size of gravel in the spawning bed, which is a function of water velocity, will also depend on the species and size of fish. Trout seldom use gravel larger than 2 inches while larger salmon use gravel up to 6 inches. The problem in most cases is one of small materials such as sand and silt (fines). The smaller the spaces between gravel, the greater the probability of reduced intragravel flows and available oxygen. Intragravel water velocity is necessary to carry off the metabolic wastes and furnish the eggs with oxygen, which is necessary for respiration (White and Bryunildson 1967). Several approaches are available for improving spawning habitat. Following are the three most successful (Hall and Baker 1982):

(1) Improving the quality of spawning gravel by removing fine sediment.

(2) Increasing the amount of spawning gravel.

(3) Providing access for spawning adults above barriers.

Efforts to increase fry production through improvement of spawning habitat may be completely negated by lack of suitable rearing area to support the additional fry (Reeves and Roelofs 1982).

In planning spawning habitat improvement projects, it should be known that the potential for negative side effects on rearing habitat exists, particularly when heavy machinery is used (British Columbia Ministry of Environment 1980). Clearing of forest debris and jams and filling in small pools, all of which provide cover and rearing space for juvenile fish, should be avoided.

Gravel Restoration

The objective of gravel cleaning is to remove material too small for spawning use--1/8-inch diameter for trout, 1/2-inch diameter for salmon--from areas used for spawning in the streambed, thus creating an environment of adequate permeability. Tests have shown that salmon survival in cleaned riffles is 40 to 60 percent greater than before treatment.

Removal of sediment from spawning beds is especially beneficial if there is reasonable certainty that sediment from upstream sources will not clog gravels in the cleaned areas before fish have an opportunity to produce. If there are no sources of fine material, natural streamflow will usually clean the bed over a period of time. Sources of fine sediment increase as the human population increases with its accompanying construction, farming, logging, and cattle and sheep grazing activities (Mih 1981). First priority should be watershed rehabilitation to eliminate the source of fines. Stream work, such as gravel cleaning, gravel placement, and structure placement, causes temporary increases in suspended solids and turbidity downstream. These suspended materials can temporarily reduce benthic invertebrate populations and fish spawning success in lower sections (Reeves and Roelofs 1982).

Mechanical Loosening. This method involves mechanically loosening gravel to facilitate spawning. Gravel may be raked, harrowed, disked, spaded, plowed, or dozed when gravel becomes cemented together or filled by fine sands or silt. When bulldozers are used, gravel is turned to a depth of 10 to 14 inches using a bulldozer quartered at a 45-degree angle across the stream, moving into the flow. The blade is tilted and angled like a plow (Gerke 1973). Succeeding passes are made downstream, stepwise, at 5- to 7-foot intervals so that displaced fine sediment will not be deposited in the cleaned area (Reeves and Roelofs 1982). Best results are obtained during the highest water flows in which the bulldozer can operate safely. The work should be timed to avoid loss or damage to eggs and larvae already in the gravel and to use water velocities that will carry finer materials downstream. Work should progress in a downstream direction. The effects on downstream values should be thoroughly evaluated.

Hydraulic Cleaning. Cleaning gravel by means of high-pressure hydraulic jets to dislodge sediments is a promising technique being used successfully in some areas, but one in need of further development before it can be recommended for general use. Under this method, the silt-laden water is collected by suction system and discharged to the streambank. Mechanical problems remain to be solved completely, but these devices are promising enough to continue development.

Manual Release of Sediments. A high-pressure portable pump and firehose can be used successfully to clean spawning gravel in a small stream (Mundie and Mounce 1978). A stream of water is directed at the streambed or into the streambed with a pipe nozzle. The displaced materials are washed downstream by the current. Adequate flows are needed to transport the sediment from the area, and sites should be restricted to lower reaches of the watershed (Reeves and Roelofs 1982).

Creating New Spawning Beds

The following methods should be used to create new spawning areas:

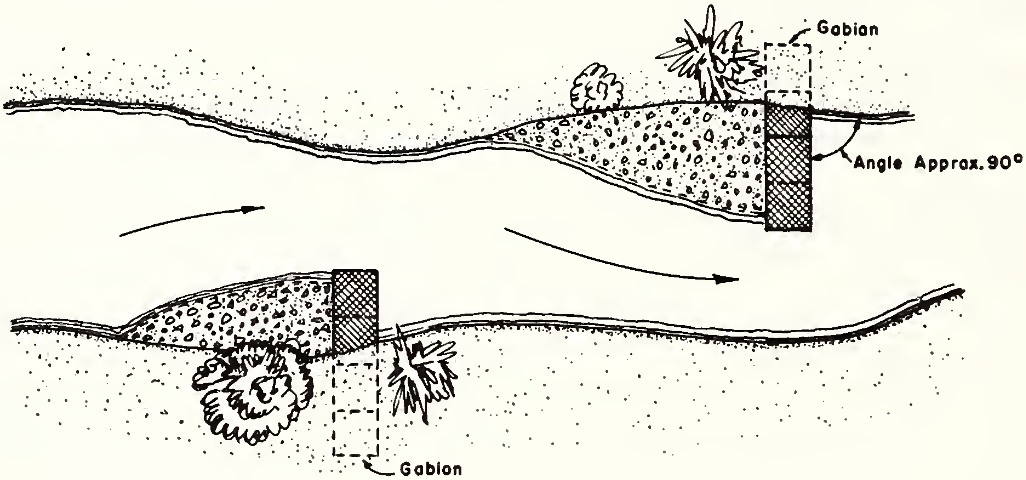
Trapping Existing Gravel. Gravel is trapped by placing various types of structures in strategic locations. Low dams or right-angle deflectors can be used as traps (Figure 1-29). Streams characterized by steep gradients with small scattered deposits of gravel are best suited for this type of improvement work.

(1) Gabions. Until recently, fishery managers have been reluctant to use gabions because of their structural instability, failure to retain material of adequate size, and blockage of upstream movement of fish at low flows (Reeves and Roelofs 1982). However, recent modifications in the design and installation of gabions have led to significant improvements in accumulation of gravel. For best results, the ends of gabions are extended 3 to 6 feet into the banks and riprapped to prevent flows from washing around the ends. The bottom gabion in the streambed is recessed approximately 1 foot and successive layers and sections are wired and cabled to trees or large rocks if present (British Columbia Ministry of Environment 1980, Reeves and Roelofs 1982, Hall and Baker 1982).

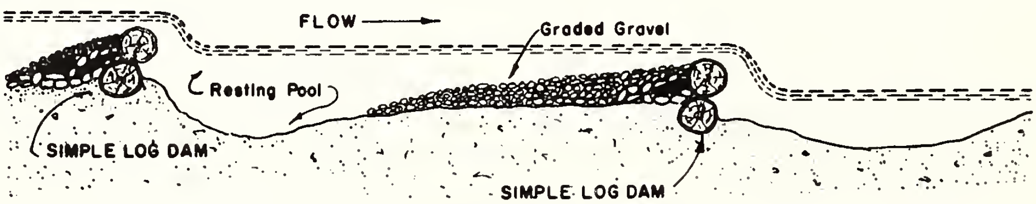
(2) Rock and Log Sills. Rock and log sill dams have been used successfully in the United States and Canada. Rock sills are formed by hand placing or bulldozing large boulders together across the stream so that silt and debris can lodge among rocks to form pools and collect spawning gravel.

Log sills usually are used on streams less than 33 feet wide. Large logs up to 3 feet in diameter are partially set into the streambank, extending logs 3 to 13 feet into the banks where they are anchored with rock riprap. Support posts are angled into the streambed and nailed to the logs. Gravel is placed behind each structure and sloped to the top. Cyclone fencing is overlaid on the post and attached to both posts and logs for stability (Reeves and Roelofs 1982).

(3) Cedar-Board Structures. Cedar-board structures are used on small streams to accumulate gravel and to provide holding areas and rearing pools (Figure 1-30). The structures usually



Traps for spawning gravels--
plan view of deflector traps



Cross section showing location
of gravel placement

Figure 1-29. Spawning gravel.

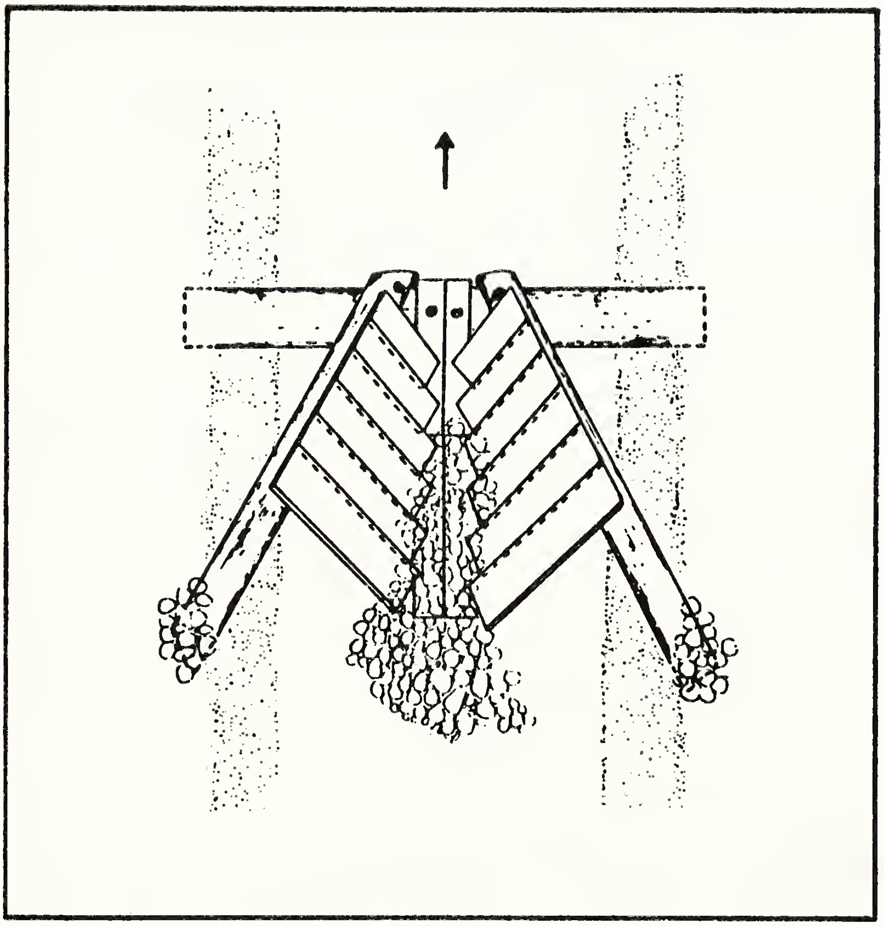


Figure 1-30. Cedar-board structures.

Source: Anderson 1978

are placed in series. The main support log is placed across the stream, anchored into the bank 3 to 6 feet and riprapped. Two side support logs are attached to the first log to form an open-ended "V," and one is angled into the banks. Boards (cedar shakes in Figure 1-30) 1 to 2 inches thick are secured to the side supports and slanted down into the streambed. Additional boards (shakes) are set perpendicular to the main support log between the side supports. The downstream edge of an upstream shake should overlap the upstream edge to the downstream shake to prevent shake displacement at high flows (Reeves and Roeflofs 1982).

Introducing Graded Gravels. In streams lacking gravels or containing only low-quality gravels, graded gravels are sometimes scoured out of structures or placed in natural stream channels to improve spawning. Introduced gravels can be protected from sedimentation by an upstream sediment basin.

Low dams, sills, or weirs should be used to hold gravels in place (see Figure 1-32). Sills and dams also are useful in regulating the depth of water over the gravels. For maximum efficiency, the gravels may have to be cleaned to remove accumulated sediments. Clean by manually or mechanically stirring or using pumps with high-pressure water jets. Cleaning should proceed in a downstream direction.

Desirable gravel depths and sizes vary with species and fish size. As a general rule, trout can best use gravel 1/4 to 2 inches and salmon 1/2 to 6 inches or more in size and occurring in deposits 8 to 18 inches deep or deeper.

Artificial Spawning and Hatching Channels. Spawning channels allow fish to enter and deposit their eggs in sections of channel selected by the fish themselves. Hatching channels are much more efficient than spawning channels in that less channel area is required to accommodate equal numbers of eggs. Hatching channels differ in that the eggs are stripped from fish and then placed in the gravel. Streamside incubators are used in place of hatching channels in some areas. The construction, operation, and maintenance of artificial spawning and hatching channels, as a means of habitat improvement, usually will be accomplished in cooperation with State or other agencies under special-use or cooperative agreements. These types of improvements involve construction of an artificial channel with controlled waterflows.

Spawning channels appear to be most valuable for anadromous salmonids that migrate to the ocean shortly after emergence from the gravel (Everhart, Eipper, and Youngs 1975). However, brook trout also successfully use artificial spawning facilities in streams of New York (Webster 1962).

Spawning channels that use river water intakes usually have all the inflow pass through a silt-settling basin before entering the channel. Fine silts and wind-blown sediments accumulate in the spawning and hatching channels that necessitates periodic cleaning of spawning channel gravel. Cleaning methods used include bulldozers, fire hoses, air-water jetting, and a spawning channel gravel cleaner (Andrew 1981).

Studies of natural spawning areas and spawning channels have corroborated the need for a stable streambed, sustained low flow, and permeable gravel. When these conditions are met, high survival of eggs and larvae usually results. The artificial spawning channel was conceived to supply this need. One of the first successful spawning channels, built by the Canadian Department of Fisheries in Robertson Creek, increased survival of pink salmon to 91 percent in contrast to 10 percent in natural spawning areas (Lucas 1960).

An example of a spawning channel was constructed at Indian Creek in Hollis, Alaska, by the Fisheries Research Institute of the University of Washington. This channel was 1,200 feet long and located in a flood plain. A low-flow stream section was chosen that provided a minimum depth of 4 inches and a minimum velocity of 1 ft/s at a stream discharge of 5 ft^3/s. Within the low flow section of the streambed, all material was removed to a depth of 1 foot below the channel bed surface and replaced with sorted gravel screened to remove material greater than 6 inches and less than 3/4 inch.

The existing 0.4 percent grade was maintained throughout the length of the channel. The final graded low-flow channel was trapezoidal with a depth of 24 inches, a bottom width of 16 feet, and a side slope of 1 to 2. The bank of the flood plain was reinforced at critical points with logs and stumps covered with gravel. Gravel on the surface of the flood plain was not altered other than adding an overburden to several feet of soft bottom on the right bank. All overhanging trees, stumps, and snags were removed from the high-flow channel. A settling pool 80 feet wide, 100 feet long, and 4 feet deep was excavated at the upstream end of the channel to restrict downstream movement of small particles (see Figure 1-29).

The flood plain channel satisfied the necessary requirements: bed stability, adequate minimum flows, and high permeability. Gravel size composition can be varied to suit the salmon species the channel is intended for. This type of channel is suitable only for streams where the expected 5-year flood discharge does not exceed 1,200 ft^3/s. At discharges higher than this, the streambed loses its stability.

(1) <u>Cost-Benefit Analysis</u>. In determining the economics of a spawning channel it is essential to know two things: first, the number of spawners it will accommodate, and second, the total cost.

The number of spawners a channel will accommodate is determined simply by dividing the bottom area of a channel by the area needed for each pair of spawners. The available data about spawning area requirements are summarized in Table 1-4. It is apparent from the table that spawning area requirements vary in proportion to the size of the fish and probably in proportion to the egg content of the female. As a result, fry production from a spawning channel will, in general, be directly related to the area of the channel, if other factors are comparable.

Some examples of costs of construction of spawning channels are given below:

(a) Jones Creek Spawning Channel

Size: 10-feet wide by 2,000-feet long, 2,200-square-yard spawning area.

Capacity: 6,300 pink salmon, or 3,150 spawning pairs, allowing about 0.7 square yard per spawning female.

Total development cost (1984 dollars):

Intake (headgate, pipe, concrete, and trash rack)	$ 15,000
Channel (clearing, excavation, gravel, structures)	19,500
Fish diversion fence across river	65,400
Dikes (between river and channel)	9,000
Contractor's overhead and profit	24,600
Total	$133,500

(b) Robertson Creek Spawning Channel

Size: 2,550-foot length of usable spawning gravel, incorporating eight holding pools, each about 40 feet long, in which fish can lie until they can reach maturity. The balance of the project provides about 100,000 square yards of spawning area.

Total cost (1984 dollars):

Intake (added to existing dam)	$ 15,000
Channel	
(clearing and grubbing)	42,000
(excavation)	105,000
(gravel)	33,000
(four, drop structures--with control gates)	171,000
(riprap)	12,000
Miscellaneous (handrails, fence, roads, bridges, temporary structures)	49,500
Total	$427,500

Table 1-4. Average area of Redds and area recommended per spawning pair of fish using artificial spawning channels (square meters).

Species	Source	Average Area of Redd	Area Recommended Per Spawning Pair
Spring Chinook	Burner (1951)	3.3	13.4
Fall Chinook	Burner (1951)	5.1	20.1
Summer Chinook	Burner (1951)	5.1	20.1
Coho	Burner (1951)	2.8	11.7
Chum	Burner (1951)	2.3	9.2
Sockeye	Burner (1951)	1.8	6.7
Pink Salmon	Hourston and Mackinnon (1957)	0.6	0.6
Pink Salmon	Wells and McNeil (1970)	0.6-0.9	2.5-3.5
Steelhead	Orcutt et al. (1968)	5.4	20.5
Steelhead	Hunter (1973)	4.4	17.0
Rainbow Trout	Hunter (1973)	0.2	0.8
Cutthroat	Hunter (1973)	0.09-0.9	0.8-7
Brown Trout	Reiser and Wesche (1977)	0.5	2-4

Source: Reiser and Bjornn 1979

(2) Site Requirements. A biologist-engineer team will inspect the proposed site for artificial spawning or hatching channels. Site must provide an adequate depth of waterflow at time of spawning, suitable water velocities during spawning and incubation, and proper gravel size and bottom areas needed to accommodate the planned-for fish species. Table 1-5 gives water depth, velocity, and substrate size criteria for anadromous and salmonid spawning areas. It is also important to choose a site where silt deposition will be minimal and to plan for an intake that will exclude bedload particles of a size of 1/2 inch or less. The key to success is careful evaluation of all factors involved. Hasty assumptions can result in failure.

Sediment Ponds. Sediment can clog stream channels and gravel beds, act as a carrier for other pollutants, and fill lakes and ponds, resulting in a degradation of aquatic habitats (Ambrose, Hinkle, and Wenzel 1983). Sediment ponds are often the final line of defense in controlling environmental siltation problems. They are commonly used at the intake of spawning channels. Sediment

Table 1-5. Water depth, velocity, and substrate size criteria for anadromous and other salmonid spawning areas.

Species	Source	Water Depth (meters)	Velocity (cm/sec)	Substrate Size (centimeters)
Fall Chinook	Thompson (1972)	0.24	30-91	1.3-10.2
Spring Chinook	Thompson (1972)	0.24	30-91	1.3-10.2
Summer Chinook	Reiser	0.30	32-109	1.3-10.2
Chum	Smith	0.18	46-101	1.3-10.2
Coho	Thompson (1972)	0.18	30-91	1.3-10.2
Pink Salmon	Collings	0.15	21-101	1.3-10.2
Sockeye	--	0.15	21-101	1.3-10.2
Kokanee	Smith (1973)	0.06	15.73	--
Steelhead	Smith (1973)	0.24	40-91	0.6-10.2
Rainbow Trout	Smith (1973)	0.18	48-91	0.6-5.2
Cutthroat	Hunter (1973)	0.06	11-72	0.6-10.2
Brown Trout	Thompson (1972)	0.24	21-64	0.6-7.6

Source: Reiser and Bjornn 1979

basins also are used in combination with general watershed stabilization to hasten recovery of streams with heavy bedloads and to protect introduced spawning gravels. Design criteria will vary from State to State, and an engineer is required to design the ponds.

Sediment must be removed from the pond when it reaches a predetermined depth. Disposal of the sediment may be a problem. Sediments can be spread with a bulldozer and seeded as a wildlife opening.

Barrier Removal Dams, waterfalls, culverts, debris jams, and rock and earth slides may pose a threat to fish migration.

Debris Jams

Contrary to popular belief, debris jams ordinarily do not block fish passage. They actually may provide shelter and create pools (Calhoun 1966), and some increase the amount of habitat available for rearing juvenile salmonids. Organic debris is an important substrate and food source for stream invertebrates. The principal damage to fisheries caused by debris jam is the sedimentation and buildup of silt and gravel behind the jam and loss of spawning areas where the jam is located.

In instances where upstream waters are actually blocked to fish, debris jams should be removed primarily to renew fish passage. In other instances, however, the purpose of such clearing programs is to permit scouring spring flows to remove the silt and gravels deposited behind the jam.

Once it is determined that debris jams need correction, the following should be considered:

(1) Assess each case on the basis of individual onsite characteristics.

(2) Prevent as much as possible further sediment deposition downstream. The possibility of downstream damage that results from release of the accumulated sediment behind jams will need evaluation.

(3) A clean, straight channel is not a desirable end product. Overzealous cleaning of debris from streams damages fish habitat. Boulders, logs, and irregularities in channels and banks all provide shelter and habitat diversity for fish. Removal of snags and debris resulted in a 51 percent reduction of catchable fish in a Missouri stream (Hickman 1975).

(4) Keep to a minimum equipment operation in the streambed and in the riparian strip. Use of hand labor and minimal light equipment is preferable.

(5) Consult State fisheries experts when developing debris jam clearance projects, and coordinate projects with the needs of other land management activities.

There are many methods for removing jams[1] (logging yarder, skyline and winch, power saws, block and tackle, explosives, and hand labor) (British Columbia Ministry of Environment 1980). As a general rule, remove as little debris as possible. It is usually easier to remove additional pieces later than to repair the damage of excessive removal. The best removal method is usually the method that does the least amount of damage to the streambank. A channel allowing waterflow should be formed once debris is removed, following the natural stream course as closely as possible (Reeves and Roelofs 1982). An experienced fisheries biologist should help with the actual operation to prevent further damage from overzealous debris-removal.

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[1]For information on debris jam removal, see Hall and Baker (1982), who reviewed debris and log jam removal in Western North America, and "Stream Obstruction Removal Guidelines," published by the American Fisheries Society in 1983.

Rock and Earth Slides

Rock and earth slides often occur in the spring and fall during high-flow periods that may coincide with major fish migrations. It is imperative, therefore, that the slide be removed or remedial work be carried out immediately to avoid harmful delay of the migration (British Columbia 1980). Often, small slides can be removed by manual effort and a few tools rather than heavy equipment. Banks should be revegetated as soon as possible.

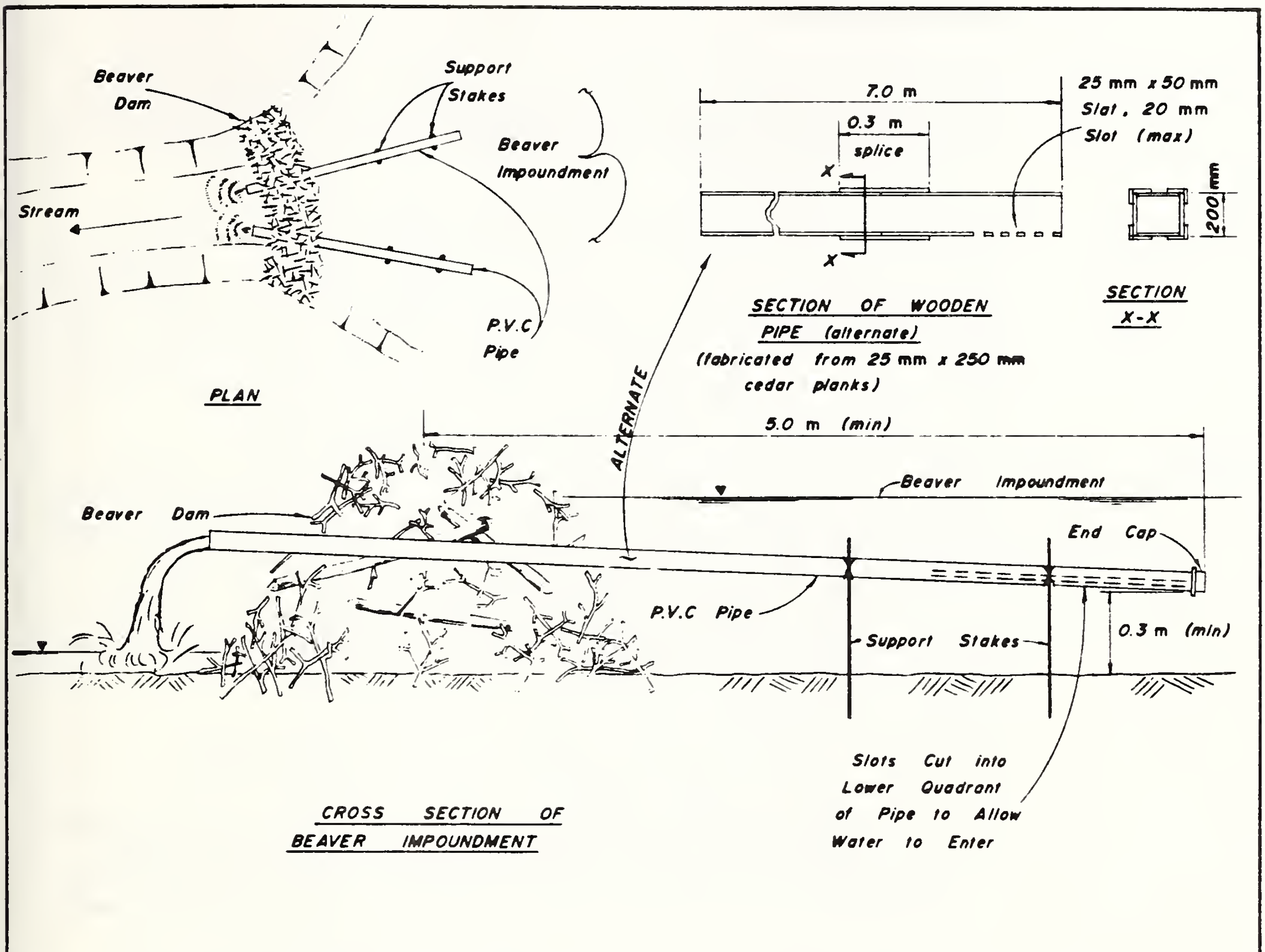
Beaver Dams

Beaver create major changes in stream and riparian habitat. For example, in the mountainous regions of the Western United States, beaver create trout habitat, including pools, on streams that otherwise would support fewer, if any, salmonids (Munther 1980). However, in the North Central and Northeastern United States, beaver impoundments serve as heat-collecting units in the summer and cold-storage units in winter, affecting survival of resident trout (Avery 1983) and posing a threat to wild trout management. Further, impounded stream segments contribute to siltation of former gravel riffles used for trout spawning and food production. The stream channel is obliterated as inundated banks lose vegetation and slump. Braided streams frequently result when a dam is removed.

Removing the dams in the North Central and Northeast States to eliminate the problems of heat and cold retention and siltation in beaver ponds generally results in the beavers' completely repairing a dam the following day. Therefore, rather than removing the dam, installing various types of drains--such as those made of perforated asbestos, polyvinyl-chloride (PVC), wood, and metal pipe--effectively controls water levels behind beaver dams.

An effective and inexpensive method of lowering the water level in a beaver pond in small streams is to install a drain by fastening together three logs 6 to 9 inches in diameter and 12- to 16-feet long with nails and short pieces of wood or metal (Figure 1-31). A piece of light sheet metal is then placed around the logs and nailed to the logs. A slot wide enough to accommodate the logs is cut through the beaver dam and the three-log drain is installed, with the long axis parallel to the stream channel and their upstream ends securely anchored. The beaver pipe described can be modified by using plastic PVC sewer or water pipe and by cutting numerous slots into the wall of the pipe to allow water to enter the pipe and discharge through the dam.

Beaver dams can be breached or removed with either simple tools, a small backhoe, or by blasting. However, when either a portion or all of a beaver dam is removed, the beaver family should also be removed.



Slotted PVC pipe can be used to drain water from a beaver dam impoundment. The pipe must be capped on the upstream end and slotted on the underside with fine openings to allow water to drain from the pond undetected by beavers. Low summer flows can be improved for rearing salmonids by the controlled release of water from the dam.

Figure 1-31. Log drain for beaver ponds.

Source: British Columbia Ministry of Environment 1980

Blasting Pools

Some success has been achieved by blasting streambeds formed in bedrock to form pools for rearing salmonids. The location of the pool must be selected to use stream velocities to avoid deposition of bedload (British Columbia Ministry of Environment 1980).

For example, in Oregon, bedrock was drilled at intervals of 1-1/2 to 2 feet to depths of 4 feet. Dynamite charges equipped with delayed action caps were used to remove the rock. Microsecond delays were used under the theory that, after the first series went off, succeeding charges would throw the rock out on the bank. Such was not the case, and a backhoe was used to remove the loose rock remaining after the blast. Some of the larger rocks were left in the pools to provide shelter for fish (Hutchison 1978).

Fishways

Fishways are manmade water passages around or through an obstruction that are designed to dissipate the water's energy so that fish can swim past obstructions under their own effort and without undue stress (Clay 1961). Noted literature on this subject includes Canadian Department of Fisheries and Oceans 1980, Bell 1973, and Orsborn 1985. Fishways have four principal components, each of which must be properly designed for each installation: the entrance approach, the entrance, the fishway proper, and the exit into the upstream water (Figure 1-32) (Mahmood 1973).

Following are some general considerations for any fishway:

(1) The fishway entrance must be easily and quickly found by the fish. Locating the fishway entrance where it will attract the fish is a critical factor. Common errors include placing it too far downstream from the barrier, too far from the main streamflow, in a back eddy, or too high for ready entrance.

(2) The fish must be able to swim through the fishway without undue effort.

(3) The fish must manage items (1) and (2) without risk of injury and delay.

(4) Flood flow hydraulics is essential information for selecting a fishway design and properly locating and anchoring it so as to minimize flood damage.

Ordinarily, fishways connected with manmade dams are constructed by the water development agency from designs provided by the State fish and game agency, the National Marine Fisheries Service, or the U.S. Fish and Wildlife Service. The role of the Forest Service in fishway construction associated with a water development project is commonly one of cooperation with other concerned agencies and the insistence that water developers provide such facilities

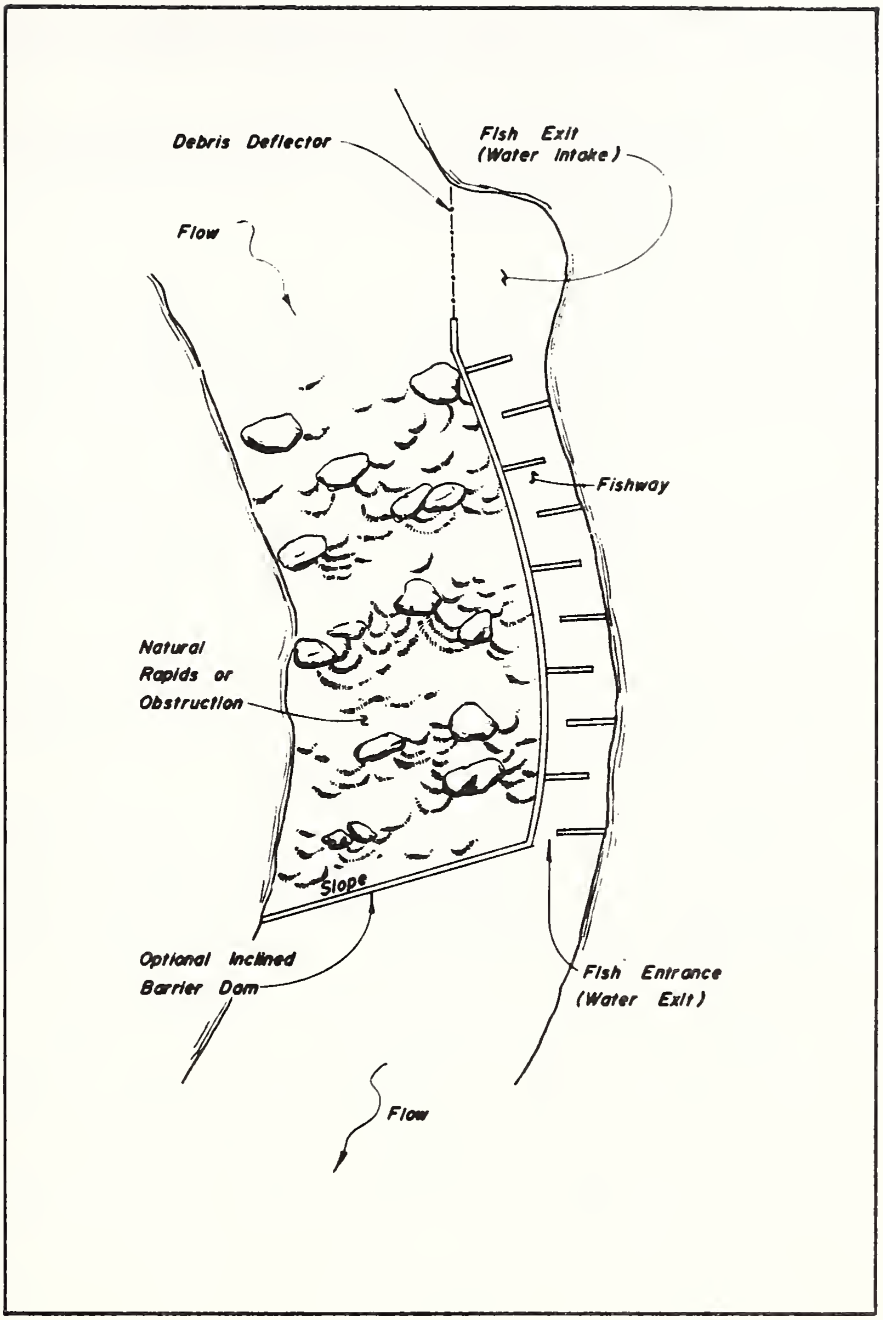


Figure 1-32. Fishway bypassing a natural obstruction.

Source: British Columbia Ministry of Environment 1980

wherever needed. There may be occasions, however, especially with passage over natural barriers, where Forest Service planning, funding, and construction will be necessary.

Clay (1961) and Bell (1973) are good references for fishways, fish screens, and spawning channels, but much of the material is quite detailed (Reeves and Roelofs 1982).

Fishway Requirements

Successful design, construction, and operation of a fishway require close cooperation between designer and biologists. While experience and good judgment are required to evaluate the needs of each specific site, good fishways have the following basic requirements:

(1) Water velocities must not exceed the swimming capacity of the fish (see Tables 1-6 and 1-7). Experience has shown that short-duration velocities of 6 to 8 feet per second for migrating salmon and 4 feet per second for trout are not excessive (Dimo 1977).

(2) Rapid changes in flow patterns must be diminished. If the head increases, the fishway must be designed so that the extra energy will be dissipated quickly and without changing the general features of the flow pattern.

(3) The fish should have ample physical and visual clearance. In no case should the smallest submerged opening be less than 10 inches wide. Fishways should be deep enough so that fish may remain hidden from view. It is advantageous to have ports at the bottom of the baffles in the weir type.

(4) Fishways that are too long for fish to negotiate in one continuous effort should have adequate resting areas. Fishways composed of a series of pools where intermittent effort is required should have resting areas in each pool. Fishways in which energy is dissipated by steeppasses require resting areas about every 10 feet of vertical rise, depending upon the shape and length. It is best to provide rest areas (about 4 cubic feet of water per fish) in which the downstream flow velocity does not exceed 1 foot per second.

(5) They should operate at all flow stages of the river without need for manual controls.

(6) Enough water to attract the fish at its downstream end must be discharged. Water at a velocity of about 3 feet per second and not more than 8 feet per second should issue from the entrance to the fishway. Physical conditions at the entrance are extremely important to successful fishway operation. The issuing water must "feel" just right to the fish.

Table 1-6. Swimming speeds of average-size adult fish (feet per second).

Species	Cruising Speed	Sustained Speed	Darting Speed
Carp	0 to 1.2	1.2 to 4.0	4.0 to 8.4
Suckers	0 to 1.4	1.4 to 5.2	5.2 to 10.3
Lamprey	0 to 1.0	1.0 to 3.0	3.0 to 6.3
Whitefish	0 to 1.3	1.3 to 4.4	4.4 to 9.0
Grayling	0 to 2.5	2.5 to 7.0	7.0 to 14.2
Brown trout	0 to 2.2	2.2 to 6.2	6.2 to 12.7
Trout	0 to 2.0	2.0 to 6.4	6.4 to 13.5
Steelhead	0 to 4.6	4.6 to 13.7	13.7 to 26.5
Sockeye	0 to 3.2	3.2 to 10.2	10.2 to 20.6
Coho	0 to 3.4	3.4 to 10.6	10.6 to 21.5
Chinook	0 to 3.4	3.4 to 10.8	10.8 to 22.4
Shad	0 to 2.4	2.4 to 7.3	7.3 to 15.0

Source: Bell 1973

Table 1-7. Fish stamina and swimming capabilities (feet per second).

Fish Size (inches)	Velocity	Trial Cruising Period (seconds)
1	0.33	20
2	0.66	20
3	1.0	20
4	1.3	20
5	1.6	20
6	2.0	20
7	2.3	20
8	2.6	20
9	3.0	20
10	3.3	20
15	5.0-8.0	20

Note: A relationship appears to exist in the length of trout and the time these fish can sustain themselves at various velocities. Interpretive information for this table was taken from the report "Design of Fishways and Other Fish Facilities" by C. H. Clay on the calculated relationship between speed, fish length, and time. For fish to pass through a culvert easily, the velocity should be less than indicated for the fish size. Salmon and large trout are capable of negotiating flows of 12 feet per second for short sections of stream (Metsker 1970).

Source: Reisner and Bjornn 1979

(7) The entrance should be at the farthest upstream point available to the fish. The exit should open into a nonturbulent pool upstream some distance from the obstacle.

It is preferable to have the entrance in a nonturbulent pool so that the water issuing from the fishway will be attractive to the fish and easily found. The entrance should be located as close as possible to areas where fish congregate below the obstruction.

(8) The upstream exit should be located so fish will not readily be swept back downstream over the obstruction.

(9) The fishway should be economical to construct and maintain and, as much as possible, should be of standard construction, easily accessible for repairs, and able to withstand the destructive action of weathering, logs, ice, and debris.

(10) The fishway should be designed to prevent sediment or debris from interfering with its efficient operation. A debris deflector should be incorporated at the water intake.

(11) The fishway must not require more water than is available in any operating season. The vertical slot design uses large amounts of water and should be avoided unless warranted by detailed and comprehensive hydrological surveys. All steeppass designs require large amounts of water and are satisfactory for falls or other run-of-the-river sites, but they are not suitable for small creeks or other places where waterflows are limited during the operating season. Weir and pool fishways should be designed for small water demand as they are the safest and simplest type for the general situation.

(12) Biological and hydrological data required before the design of a fishway (British Columbia Ministry of Environment 1980) include:

(a) The salmonid species and the magnitude and timing of the runs.

(b) The probable access route to the barrier, including the areas where fish will congregate below the obstruction.

(c) The extent of spawning and nursery areas and the potential salmonid production from both above and below the obstruction.

(d) The type and quantity of anticipated debris.

(e) The frequency, duration, timing, and magnitude of various types of flows, especially extreme high and low flows.

(f) The location of other barriers in the stream system, and their possible effects on distribution of salmonids.

Fishway Design

Following are design considerations for weir and pool fishways:

(1) Water discharge should not hinder the swimming movement of the fish; a depth of 6 to 12 inches over the top of the weir usually is recommended for small fishways. There must be enough water flowing through the fishway to attract fish at the entrance. A slotted entrance portal requires a velocity between 3 and 8 feet per second. A very rough criterion of adequate discharge is that it should be about equal to the cross-sectional area of the pool in square feet.

(2) Notches in the weir crests reduce the quantity of water required for fish passage. Also, fish not able to jump into a steep overfall jet may be able to swim through the crest notch. The notch depth should equal the crest differential (see item 3).

(3) Crest differential is the difference in elevation of successive weir crests. Ordinarily, this differential should be in the 12-inch range. Increasing the crest differential increases the upper limit of plunging flow, making it more difficult for the fish to get over the weir. Also, the flow is more unstable than it would be for smaller crest differentials.

(4) Ports at the bottom of the weirs will pull the overfalling jet farther down into the pool. Also, ports provide an auxiliary passage for the fish in transit. Making the ports too large will increase the discharge and make the pools very turbulent. A 10- by 12-inch port is adequate for weirs 2-1/2 feet wide and 30 to 36 inches high.

(5) It is not advisable to change the crest shape from the conventional square crest because of the frequent necessity of varying the crest height in small fishways.

(6) Fish prefer to remain in shaded and dark areas while traveling through fishways.

(7) The following relationships between crest differential and pool dimensions are suggested as the minimum sizes that will prove adequate for fish passage: width, 2-1/2 times crest differential; length, 10 times crest differential; depth, 3 times crest differential.

(8) When fish will be swimming through high-velocity water, changes in direction should be minimized.

(9) Energy dissipation must be complete, with no carryover from pool to pool.

Types of Fishways

Three basic types (Figure 1-33) and two modifications of fishways are widely accepted:

Pool-and-Weir Fishways. The pool-and-weir fishway consists of a series of vertical partitions installed at intervals down the length of a specially constructed channel or flume (Figure 1-36). Water flows over the top of the successive partitions, each slightly lower than its predecessor, creating a series of step-like pools that the mature salmonid can ascend with ease. The pools must be carefully sized to dissipate the energy of the cascading flow. Pool-and-weir fishways are most effective where water levels remain fairly constant (British Columbia Ministry of Environment 1980). Where water levels fluctuate, they require regular adjustment at the upstream end to provide the optimum rate of flow. The weir-type fishway allows water to flow over the crosswalls, called baffles, that act as weirs. Fish proceed from "step to step" by swimming over the baffle.

Pool-and-Orifice Ladders. A pool-and-orifice ladder is a modification of the pool-and-weir ladder. It provides orifices in the downstream walls of each pool. The water passes through the orifice and, in some designs, also overflows. This type of ladder was designed for situations where the flow fluctuates considerably. In the absence of orifices, the full head will pour down the ladder, making it difficult or impossible for fish to ascend during high flows. The orifices lessen the effect of high flows by passing proportional amounts of the head through the pools. A combination of pool-and-orifice at the top of the ladder and pool-and-weir at the bottom is often desirable. In such cases, the top pools with orifices should be roughly twice the height of the maximum depth of flow entering the ladder.

The orifices should provide about 4 square feet of opening at the bottom of the weirs. If the orifices are too large, the ladder will fail to reduce water velocities effectively. There is less flashboard adjustment required with the orifice ladder than with the pool-and-weir ladders. The orifice ladder is generally easier for fish to ascend because they do not have to jump over the weirs. Its principal disadvantage is a tendency to plug with debris at high flows, and it is difficult to clean. There is no theoretical limit to the height of pool-and-weir or pool-and-orifice ladders as far as the fish are concerned. Other factors generally limit the practical height to about 100 feet.

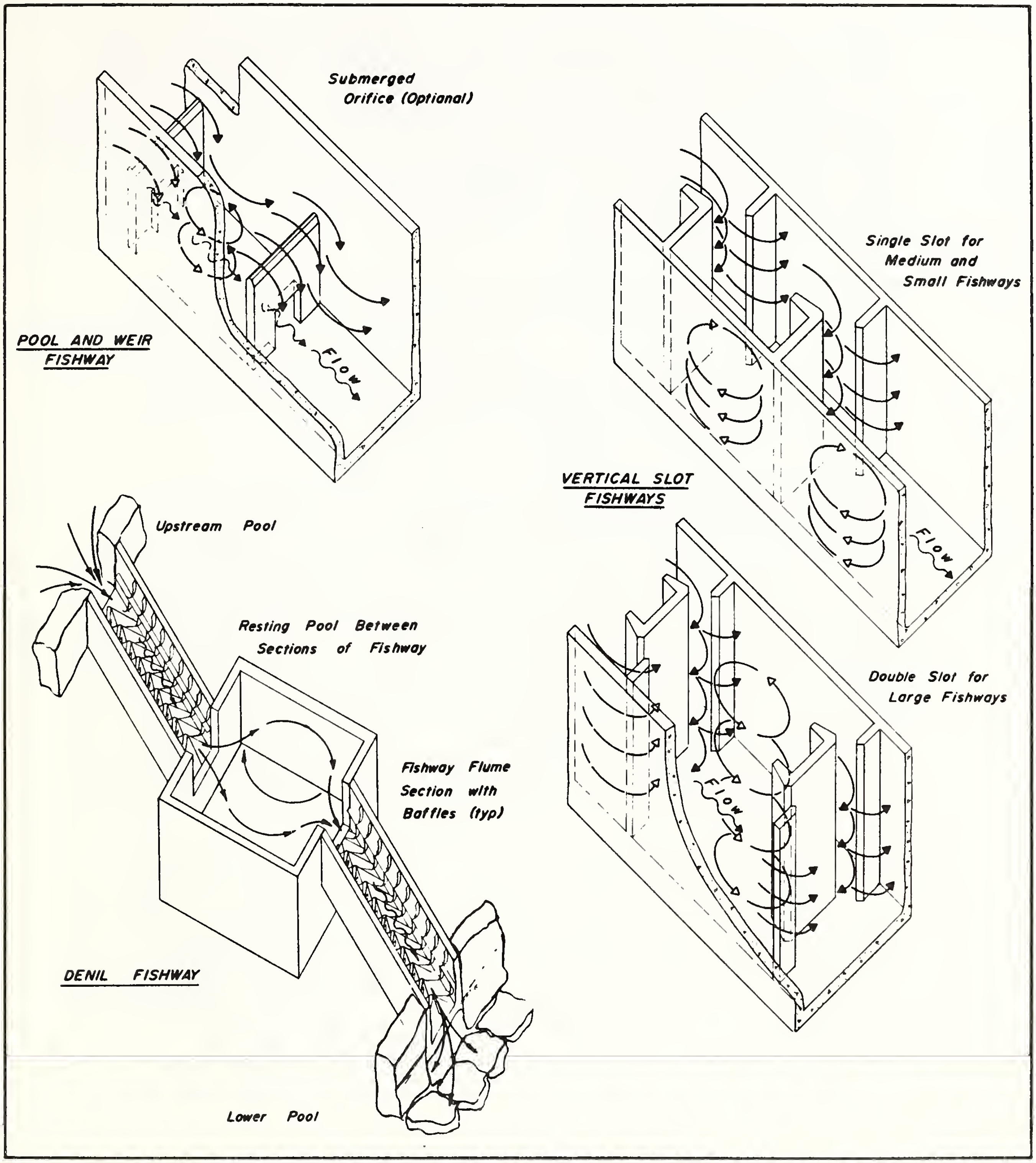


Figure 1-33. Three types of fishways: pool-and-weir, denil, and vertical slot fishways.

Source: British Columbia Ministry of Environment 1980

Denil. The denil fishway design works on the principle that water will slow down if one can turn it around. Lateral baffles project at an angle from each side and usually from the bottom of a straight chute, with clear passage up the middle (Figure 1-33). Denils are usually built over low barriers, although the State of Maine has one 50 feet high. They are constructed with resting pools between denil units. They have good entrance characteristics because of the flow pattern, and they pass debris well. Adjustment and maintenance are minimal.

Denils are ideal for streams flowing under 1,000 cubic feet per second. They are unsuitable if water levels fluctuate more than about 3 feet, unless used in combination with a pool-and-orifice fishways. Individual units should not be higher than 8 feet. Resting pools between units permit greater heights. The denil fishway is particularly suited to situations where most expensive conventional fishways would not be warranted.

Alaskan Steeppass. The steeppass, an improved version of the denil, is designed to pass fish over low head barriers. It is smaller than the denil and can be portable. Sections of the steeppass are 10 feet long and cost about $800 to $1,000 (1984 dollars). The Alaskan steeppass reduces velocities more effectively than the denil fishway, can be prefabricated from lightweight aluminum, and is easily installed. This portable type of denil fishway can be used to assess the potential of a site before the installation of a larger and more expensive fishway. Sections of the aluminum fishway can be connected to provide relatively steep passage over natural and artificial obstructions. The denil and Alaskan steeppass operate where water levels vary, allowing fish to swim at various depths. If properly installed so as to protect them from flood flow damage, Alaska steeppasses can have a design life of 25 years or more.

Vertical Slot Fishway. The vertical slot fishway also creates a series of pools and drops, but its flow passes from pool to pool through narrow slots, extending the full height of the partitions (Figure 1-33). The vertical slot fishway is self-adjusting to flow levels. It provides passage for the fish through a range of changing volumes or water levels in the stream, without requiring adjustment of stoplogs or baffles, as in the case of the weir fishway (British Columbia Ministry of Environment 1980). These are desirable features, particularly for coastal streams with extreme discharge fluctuation and for the many fishways that are relatively isolated.

Falls Modification

Falls have been modified by blasting, creating jump pools, or both, to improve fish access. Falls modification projects should not be undertaken without considering the total potential impact. Visual

characteristics and recreation potential should be included in the project evaluation (Steiner 1983).

Fish Locks and Elevators

These are used mainly for passing small runs of fish over high barriers. At fish locks, fish enter a chamber at tailwater level or from a short fishway. Water fills the chamber until the chamber's water surface reaches or comes sufficiently close to reservoir level, permitting the fish to swim into the reservoir above the dam. It is similar to a navigation lock. Fish elevators are any mechanical means of transporting fish upstream over a dam, such as tanks, tanks on rails, tank trucks, and buckets and cages hung on cable, including the means of collecting and loading the fish into the conveyance.

Because these structures are complex in design, each situation for which they are considered must be evaluated individually and thoroughly. An evaluation of ecological consequences is imperative because populations of endemic fish will be mixed. Consideration of engineering problems and requirements also must occur early in planning because construction costs, and particularly operating costs, may be excessive for the application under consideration. Two fish locks cost about $1 million (in 1984 dollars). Detailed discussions of fish locks and elevators are given by Bell (1973), Clay (1961), and Mahmood (1973).

Fish Screens

Screening devices are commonly used to prevent fish from entering water diversions (for example, canals, intake towers, tunnels). They are particularly valuable in situations involving small streams with large volume diversions. Streams with anadromous species are particularly vulnerable to fish losses by diversions.

Fish screens are installed and maintained in connection with water developments, not as a direct stream improvement. Special-use permits and Federal Energy Regulatory Commission (FERC) license applications should be examined closely for water diversions on National Forest lands to determine the need for and type of protective fish screen.

The numerous fish screen and barrier designs offer varying degrees of effectiveness and ranges of applicability. The devices can be divided into two categories: those that impose an absolute physical barrier to fish movement and those that take advantage of behavioral characteristics to restrict fish movement. Those structures intended to be absolute barriers are the revolving drum screen, perforated plate screen, parallel bar screen, rotating disk screen, link belt screen, horizontal traveling screen, inclined plane screen, passive intake screens, electric fences, high-capacity sand filters, perforated pipe filters, and barrier dams (Burns 1966; Clay 1961; Leitritz 1952; Nelson et al. 1978). The louver diverter (Rhone and Bates 1970) and fish excluder (Nelson et al. 1978) are behavioral barriers.

Few adverse effects result from the installation of fish screens. From a biological perspective, fish losses incurred because of a screening device would have occurred whether or not the device was present. From an engineering perspective, fish screens cause a loss of hydraulic head; appropriate design can control this loss. In addition, fish bypasses may result in a loss of available water, an important consideration in irrigation diversions (Clay 1961). Losses can be reduced only by incorporating the best technology available.

Several questions must be considered in the design of a fish screen: how wide and deep should the intake conduit be; what mesh and wire size are appropriate; how large should the bypass opening be; and where should the screen be placed? The answers depend on the swimming ability, physical size, and behavior of the fish (Clay 1961). The maximum allowable approach velocity is limited by the cruising speed of the fish species involved, and the design specifications for the actual screen and bypass are determined by the physical size and behavior of the species. The design criteria for the other devices are unique to each, and the swimming ability, size, and behavior of fish may or may not be important considerations.

If screen installations are desirable, State fish and game agencies, the National Marine Fisheries Service, or U.S. Fish and Wildlife Service should be contacted for information concerning costs and designs.

Turbine Bypass

A turbine bypass diverts downstream migrating juvenile salmonids from hydroelectric turbines into a collection facility or bypass channel (Figure 1-34). Smolt mortality at a dam varies depending on the amount of water discharged over the spillway as compared to the amount passed through turbines. Most fish that pass over the spillway are not injured, but those passing through the turbines suffer significant mortality. Up to 80 percent of the downstream migrants entering a turbine can be diverted.

Culverts

Improperly installed culverts can obstruct fish passage. In addition to proper placement in the streambed, structural modifications of culverts may be necessary to avoid fish passage problems. One of the most common problems associated with culverts is the formation of a drop at the downstream end. Elevated outlets usually result when culverts are installed without due consideration for the stability of the channel downstream. Dane (1978) stated that excessive water velocity, insufficient water depth, elevated outlets, and debris accumulation are causes of obstruction at culvert sites.

The two most important considerations for culvert installation are maximum acceptable water velocity and minimum acceptable water depth (Evans and Johnston 1980). The criteria for both of these conditions depend on the species. For a culvert of moderate

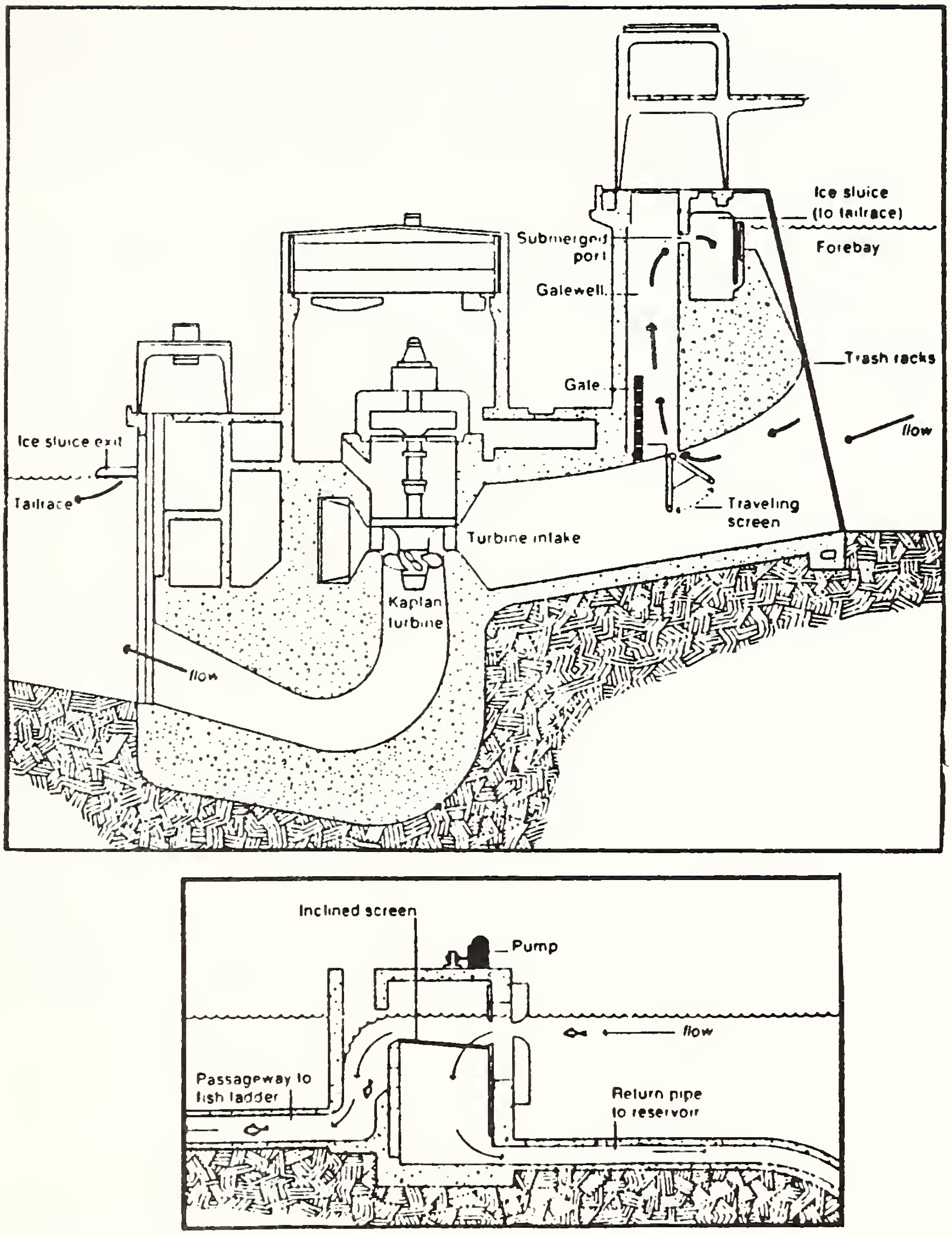


Figure 1-34. Turbine bypass.

Source: Nelson et al. 1978

length, the mean velocity of the flow should not exceed the fish's sustained swimming speed (the speed a fish can swim several minutes, ranging from 4 to 7 body lengths per second). For culverts longer than 165 feet, the mean flow velocity should not exceed a fish's cruising speed (the speed at which a fish can swim for an hour or longer, ranging from 2 to 4 body lengths per second) (see Tables 1-6 and 1-7).

Although baffles may greatly facilitate fish passage through a culvert, Evans and Johnston (1980) recommend avoiding their use, if possible, because of increased maintenance requirements. However, baffled culverts are necessary if mean flow velocity is in the lower range of the fish's burst swimming speed (the speed at which a fish can swim for a few seconds, ranging from 8 to 12 body lengths per second). Should baffling be necessary, offset baffles, vertical slot designs, and spoilers can be used (Figure 1-35) (Dane 1978, Engel 1974, Evans and Johnston 1980, Watts 1974).

A culvert outfall may be corrected by providing for one or a series of downstream gabions, rocks, logs, or concrete weirs, cribs, or low head dams of 1-foot rise (Figure 1-36). Replacement may be the best approach when a culvert hinders or blocks upstream access.

From the fisheries standpoint, the most desirable type of culvert has a bottom consisting of native material. The corrugated metal arch culvert is the most common of this type. Detailed descriptions of culvert design and installation considerations are given by Dane (1978), Engel (1974), Evans and Johnston (1980), McClellan (1970), and Watts (1974).

Based on review and resolution of fish passage problems through culverts in British Columbia, Dane (1978) developed fish migration requirements and design criteria for designing and installing culverts:

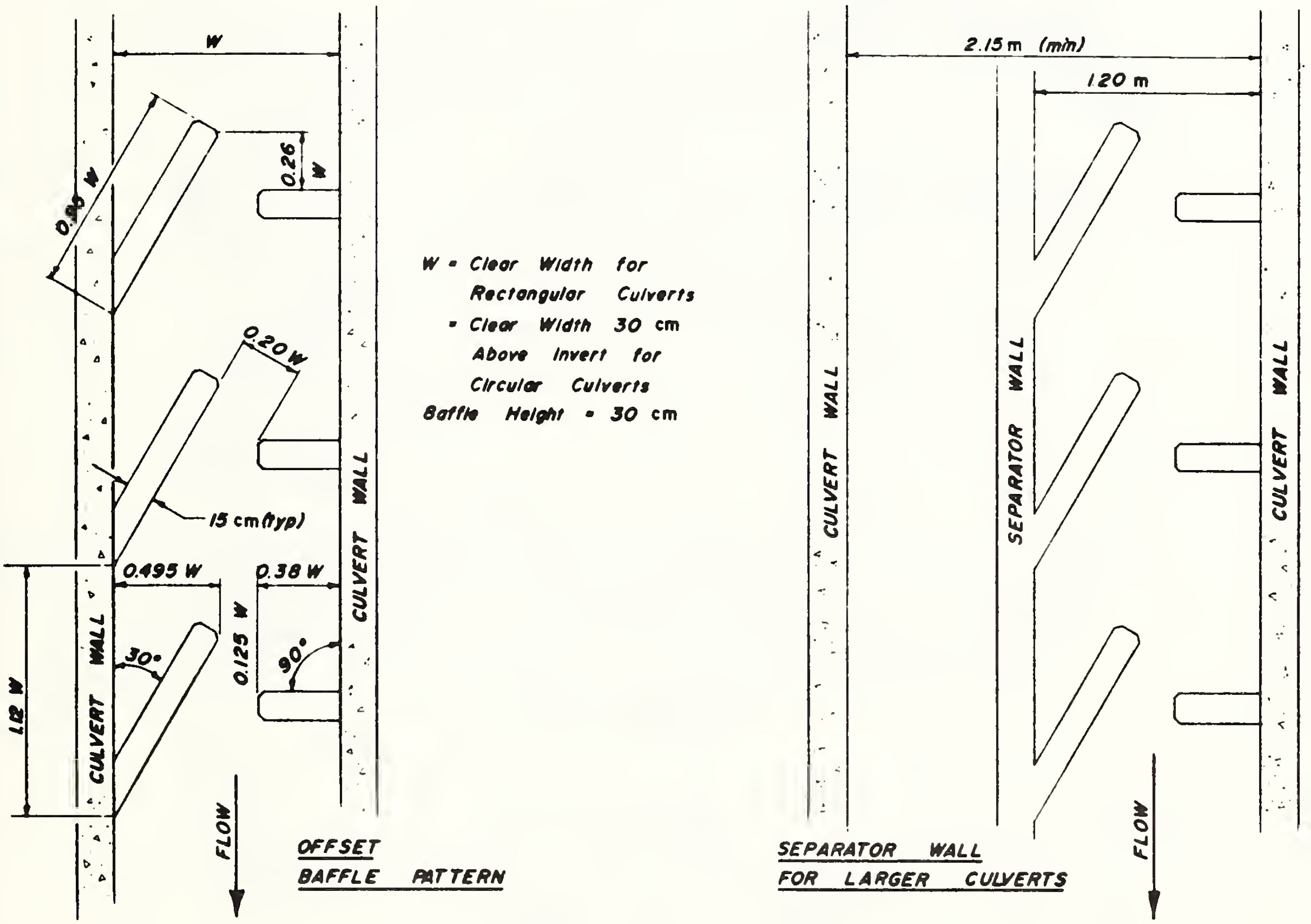
(1) Velocity. The average water velocity in the culvert should not exceed the following values:

    (a) For culverts less than 80 feet long, average velocity should not exceed 4 feet per second for salmonids and 2 feet per second for warm-water fish.

    (b) For culverts greater than 80 feet long, average velocity should not exceed 3 feet per second.

    (c) For culverts greater than 200 feet long, special consideration should be given to each site, and the fisheries agency should be consulted.

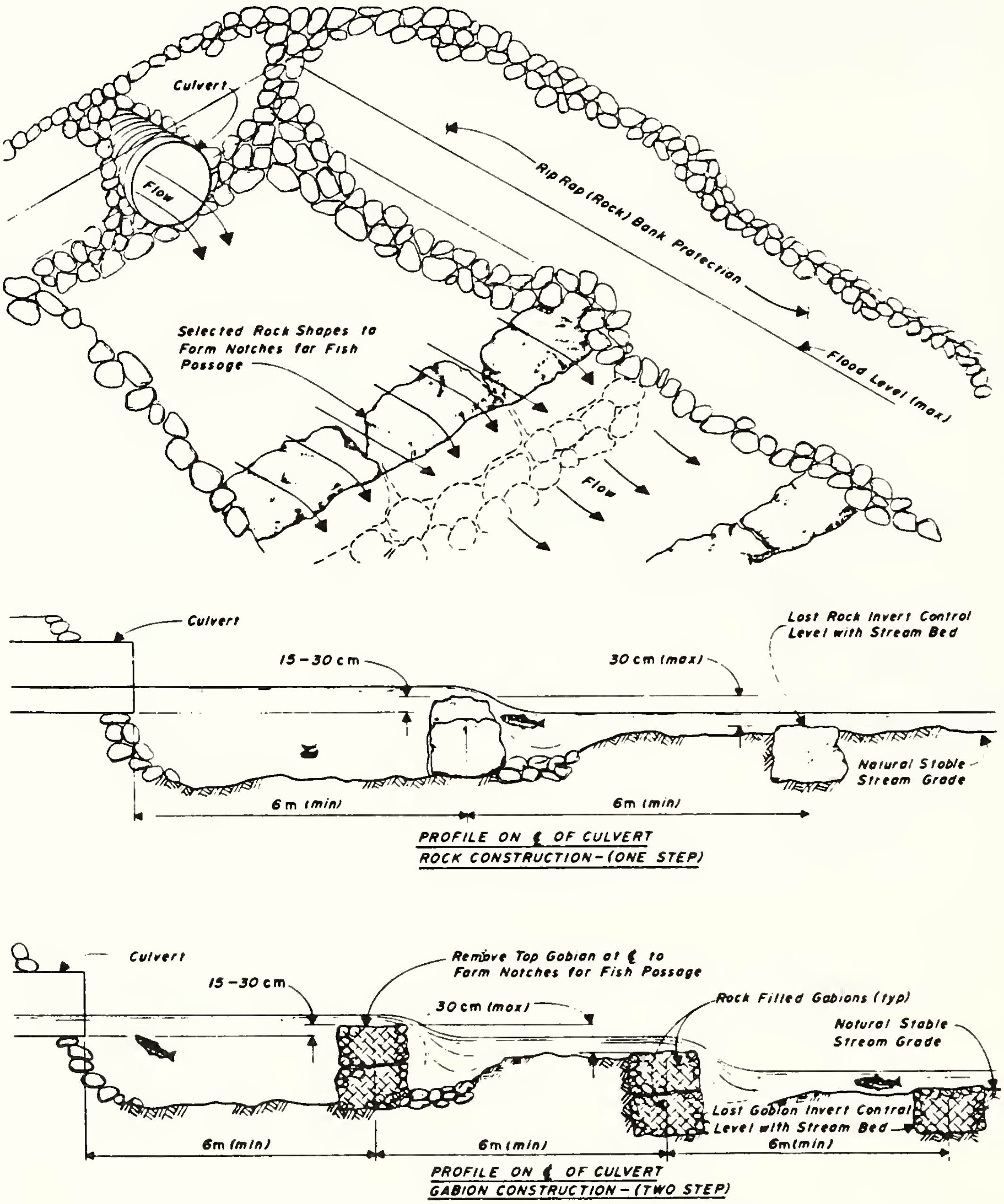
(2) Water depth. Water depth should not be less than 3/4 foot at any point within the culvert. Depth should always be great enough to submerge the largest fish that may use the culvert.



Fish passage through culverts can be improved by installing offset baffles on the bottom of the structure. Divider walls can be used in conjunction with offset baffles for culvert widths exceeding 2.15 metres.

Figure 1-35. Baffles for culverts.

Source: British Columbia Ministry of Environment 1980



Backflooding a culvert to eliminate the downstream drop to improve fish passage. The banks and stream bed must be stabilized with large rock (rip-rap) or rock filled gabions.

Figure 1-36. Backflooding culverts.

Source: British Columbia Ministry of Environment 1980

(3) Water Surface Profile. A sudden drop in the water surface profile at any point within culvert influence should not exceed 1 foot.

(4) Migration Delay. During upstream fish migration, the period during which the foregoing conditions are not met at the culvert site should not exceed 3 consecutive days in an average year.

(5) Capacity. Culvert facilities should be designed to accommodate the 100-year flood, defined as the discharge event having a recurrence interval of 100 years.

(6) Slope. The effective slope[2] of the culvert at any point along its length should not exceed 0.5 percent for a culvert greater than 80 feet long, unless appropriate compensation is made by the addition of baffles within the culvert. In culverts less than 80 feet long, effective slope should not exceed 1 percent unless baffles are added. Culvert slope should not exceed 5 percent at any time, even with baffles.

(7) Installation Below Grade. The culvert should be installed so that the bottom of the structure is at least 1 foot below the natural grade line of the stream.

(8) Outlet Pool and Tailwater Control. An outlet pool with tailwater control capabilities should be constructed at the downstream end of the culvert. Length and width of the outlet pool should be twice the diameter of the culvert, and the bottom elevation of the pool should be at least 2 feet below culvert invert elevation of the outlet.

The crest elevation of the tailwater control device should be sufficient to provide a minimum depth of 3/4 foot throughout the culvert during the lowest stream discharge anticipated, or at least 3/4 foot above the lowest elevation in the culvert fishway or baffle structure.

A small notch or depression should be provided at the tailwater control device to ensure that a passageway of sufficient depth for fish migration is available at minimum flows.

Tailwater control facility can be a barrier to walleye passage. Please review the section on culverts to be sure it provides for walleye passage.

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[2]Effective slope is defined as the mean gradient of the water surface profile between a point located at the culvert inlet and the tailwater control point below the culvert outlet.

(9) Culvert Baffles and Fishway. Baffles should be constructed in the culvert baffle if the slope of the culvert exceeds the criteria outlined above. Offset baffles are recommended for this purpose.

(10) Multiple Installations. When more than one culvert is provided, fish passage criteria need only be applied to one of them. The culvert to which fish passage criteria are applied should be installed at least 1 foot lower than the other culvert(s).

Side Channel and Pond Development

Most larger river systems have side channels and oxbow ponds that may be cut off from the main river. In Western North America, the side channels are frequently important spawning areas for salmon and trout. Inadequate water flow is generally the factor limiting fry production in a side channel. Enhancement procedures may be taken to increase flow, thus increasing fry production (British Columbia Ministry of Environment 1980). For example, in Alaska, isolated oxbow ponds are connected to the river channel allowing access to salmon thus increasing the available rearing area in the drainage.

STREAMSIDE IMPROVEMENT AND MANAGEMENT

Resource managers should carefully protect streamsides, particularly when development or utilization projects are contemplated adjacent to streams. Timber cutting, grazing, farming, road construction, and maintenance operations must pay special attention to protection of the streamside. As Hynes (1975) stated, a stream and its valley are an inseparable ecological unit. Intelligent management of all resources within a basin is the key to maintaining stream systems that are characterized by productive habitats (Richards 1964). The streamside, with its riparian vegetation, is particularly appropriate to the adage "an ounce of prevention is worth a pound of cure." Consider the streamside as two elements: the streambank and the riparian vegetation.

Riparian Vegetation

Riparian vegetation is an important element of the fishery habitat. Following are its many functions:

(1) It serves as a buffer strip to block soil movements and to trap and filter out silt. The root mats bind the soil in place to provide soil stability and reduce bank erosion.

(2) Trees and shrubs adjacent to streams provide both direct and indirect fish cover. When roots extend into or branches overhang the stream, direct fish cover is afforded. Shade from tall vegetation provides indirect cover since fish are camouflaged by shaded waters. Banks well stabilized by vegetation allow for some undercutting that provides excellent hiding places for fish. In many areas, this aspect of shade is very important.

(3) The shade provided by trees and shrubs is usually beneficial in helping to keep water temperatures low (Brown 1976). With the exception of streams at very high elevations in the West, and streams in parts of Alaska, most trout streams on National Forests benefit from factors that maintain or reduce temperatures.

(4) Detritus formed from terrestrial plants is a principal source of food for aquatic invertebrates, and eventually for fish (Meehan et al. 1977). This is especially important in headwaters where most energy comes from terrestrial sources.

(5) Trees, shrubs, and herbaceous vegetation along streambanks provide resting, feeding, and breeding places for an abundance of insects including both land insects and terrestrial stages of aquatic insects. These insects provide a substantial portion of fish diets (Cummings 1974).

Methods of Improving Riparian Vegetation

Riparian vegetation can be improved by manipulating or by planting desirable species. Plantings are made to increase the number or quality of existing plants, or to replace those disturbed or destroyed. A general rule is to plant only native species, but there are important exceptions to this.

Planting Willows on Streambanks. Some of the best plants for streambank planting are the various species of willows. Fresh cuttings should be made while the willows are dormant and, when appropriate, the cuttings should be immediately planted. An alternative is to obtain willow cuttings in the fall and "heel in" the ends in damp sand where they will not freeze. By spring, a callus is formed on the butt end and the cuttings are then known as "hardened" cuttings. Both types of cuttings have been successfully used; however, the use of hardened cuttings is recommended by some authorities. Rooting success may be increased by dipping cuttings into a commercial root-growth hormone.

Best results from willow cuttings are obtained when they are planted on mud or silt bars, or along exposed banks, where the lower end of the cutting is in permanently wet soil. Willows require periodic basal pruning to maintain the dense stands of saplings necessary to have a continuous "root revetment" (White and Bryunildson 1967).

Planting Native Vegetation on Streambanks. When beaver, muskrat, or deer are too abundant, it is usually impossible to successfully establish willow cuttings. It then becomes necessary to use other plant species for streamside plantings, and best results are usually obtained by using native vegetation, particularly shrubs and grasses. Trees should not be planted except where there is

reasonable evidence that summer water temperatures are lethal and that temperatures can be reduced only by shading with trees (White and Bryunildson 1967).

There are sites where dense thickets of woody riparian vegetation, through judicious thinning, may be made more productive of insects without impairing their usefulness for shade.

Improvement planners should refer to regional reseeding guidelines for appropriate plant species and methods of planting. Additional information concerning methods and species may be obtained from Forest Service silviculturists and range ecologists, county agents, State agricultural colleges, the U.S. Soil Conservation Service, or the U.S. Fish and Wildlife Service.

Planting Grasses to Stabilize Streambanks. Grasses are also one of the best vegetation types for riparian plantings. Grasses mixed with broad-leaved annuals should be used to stabilize streambanks and protect them from erosion if they are not too steep. Native species or exotics adapted to the area for the intended purpose should be used. For example, reed canary grass (*Phalaris arundinacea*) has given excellent results along the wet margins of streams in some localities. As small areas are usually involved, broadcasting by hand and raking in with an ordinary garden rake is a practical way of doing streambank reseeding jobs. Consider downstream effects of such vegetative plantings.

Streambanks should be revegetated concurrently or immediately following all activities that disturb or destroy riparian vegetation. Fast-growing grasses, legumes, and forbs should be planted to give quick protection. At the same time, however, slower growing plants that will eventually take over should be included. Mulching of the seeding area may be needed.

Riparian Vegetation and Livestock Grazing

Domestic livestock grazing is a major land-use activity in many areas of the United States. The loss of riparian vegetation and sloughing and collapse of streambanks caused by improper livestock grazing is probably the greatest effect of livestock on fish populations (Platts 1981). Elimination of vegetation and caving of overhanging streambanks by livestock are among the principal factors contributing to the decline of native trout (Behnke 1977). Secondary effects of overgrazing may result in increased runoff from uplands and reduced in the stability of stream channels (Brinson et al. 1981). The effects of livestock grazing on fish and the aquatic environment are described by Armour (1977), Meehan and Platts (1978), and Platts (1981).

Rehabilitation of aquatic and riparian habitats adversely affected by livestock grazing is possible (Riparian Habitat Committee 1982). Where there is livestock grazing, initial revegetation work will

usually require complete protection. To accomplish this, fencing riparian pastures on strips of streambottom is effective. Crossings and water gaps (Figure 1-37) should be installed as necessary to provide watering places for livestock.

The frequency of water gaps will depend on the character of the surrounding terrain and its effect upon livestock movement. Water access should ordinarily be provided at least every 1/3 mile. Riparian pastures and stream bottom fences not only are beneficial in aiding the establishment of streamside vegetation, but are an important stream improvement measure through their protection of the existing vegetation. Their construction may be justified on this basis alone. These fences may also serve as allotment pasture division fences, thus aiding in livestock management. They should be set back sufficiently from the stream to enable fishermen to travel along the streambank and to protect streamside vegetation. Although barbed wire is usually used for fencing, buck-and-pole or worm fences are recommended for the Western United States. These fences allow fishermen ready access and are visually preferred. Strategically located stiles (Figure 1-38) should be built, where needed, for fishermen access.

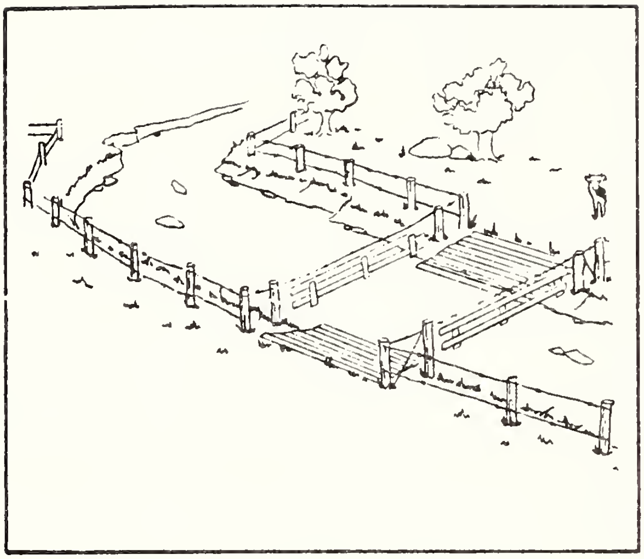
The need to maintain fenced streambottoms, after establishment of vegetation, is determined by the degree of livestock control on adjacent range.

The protection of streamside vegetation from adverse effects of road construction, timber cutting, and fire is a measure handled through coordination with other resource activities and does not come within the scope of this publication. Nevertheless, the importance of such coordination cannot be overemphasized. Probably no other single factor contributes more toward protection of streams from sedimentation than an adequate stand of streamside vegetation.

Bank Protection

Because streambank erosion is a common problem and structural protection is expensive, a coordinated effort by both watershed and fisheries management is often the most practical approach. Streambank stabilization can have pronounced effects on the physical and chemical characteristics of the stream (Stern and Stern 1980).

From the standpoint of fisheries habitat, riprap, gabion mats, or gabion and log revetments are usually less desirable than other instream structures. These structures have a tendency to speed up water velocity and reduce hiding places for fish since they do not project into the channel. However, if bank erosion is a serious threat and deflectors (jetties) or plantings will not stabilize the banks, the above structures may be necessary.



Fencing of a stream can be an important step in minimizing erosion of the stream banks. However, in order to allow livestock access to drinking water, areas must be provided that will allow easy, but protected, access to the stream. To minimize stream damage in the watering area, access ramps or platforms are constructed of railroad ties. Hanging flood gates may be placed above and below the watering or crossing area.

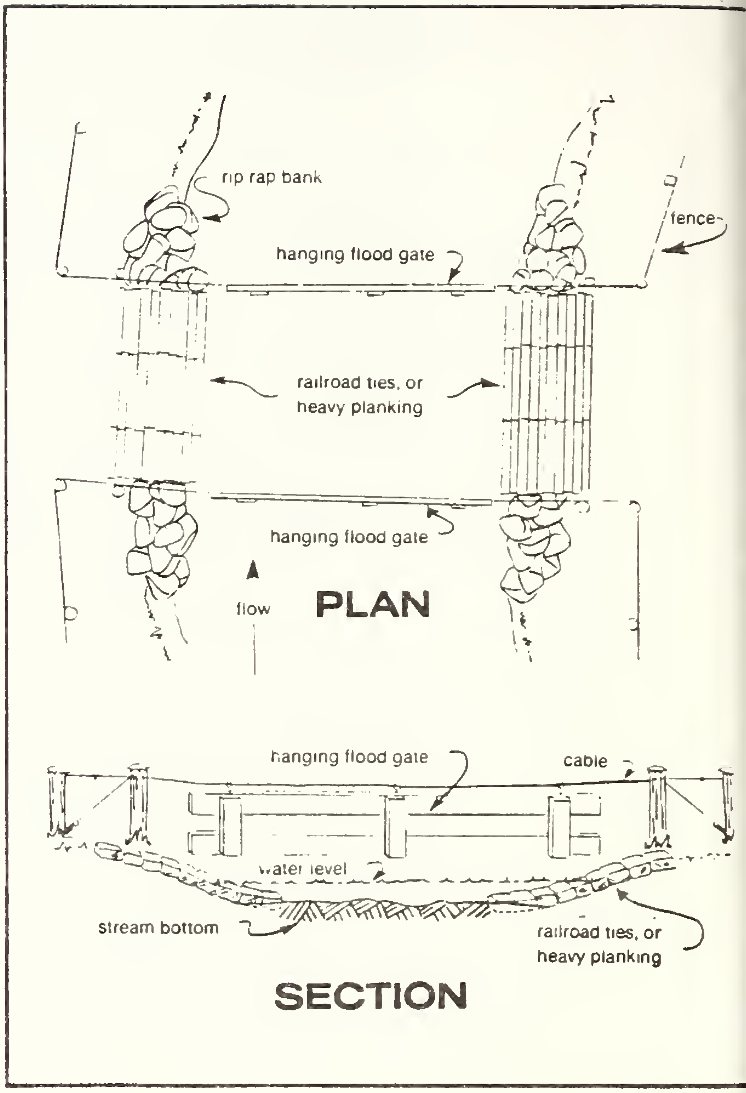
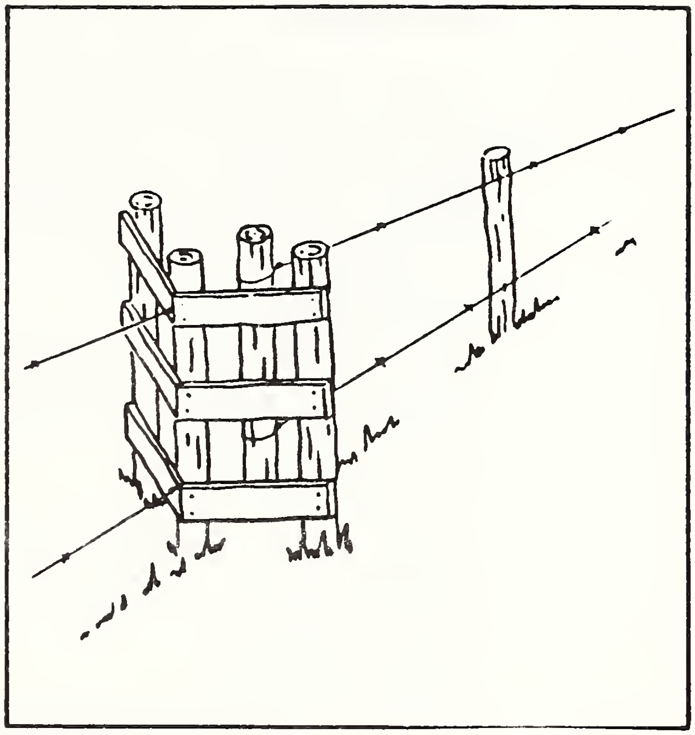


Figure 1-37. Fencing streams and crossing.

Source: Miller and Tibbott 1974



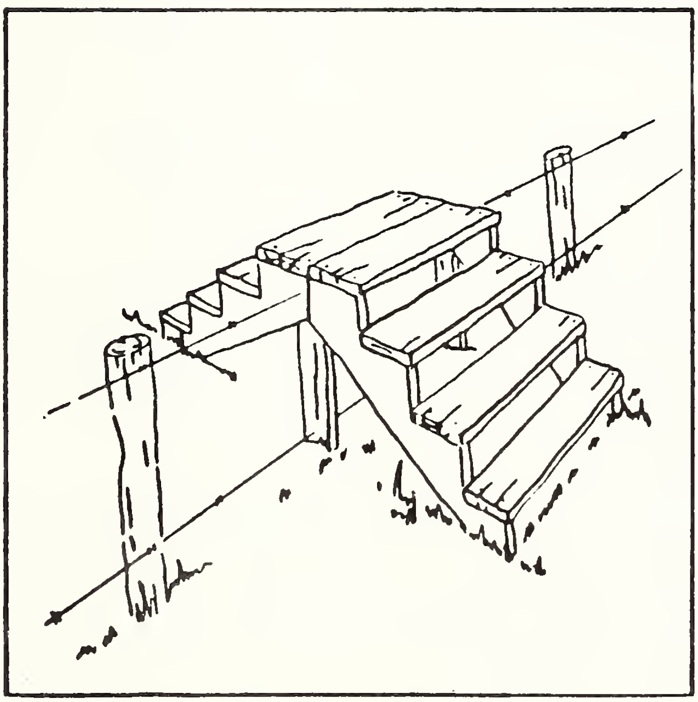


Figure 1-38. Stiles.

Source: Miller and Tibbott 1974

Rock Riprap

Large rock is commonly used to prevent bank erosion adjacent to roads. Comparatively, rock riprap (rock revetment) is less costly than gabion mats or revetments. When possible, riprap should be supplemented with rock deflectors to create an irregular bank pattern. Specifications for size of rock materials should be obtained from engineering personnel.

Gabion Matting

The use of fractional size gabions to form mats along sloping streambanks has proved very effective in protecting eroding banks (Figure 1-39). Mats are usually less expensive than other forms of revetments.

Instructions for installing mats are similar to those for other gabion structures. It is important that basket lids be closed in a downstream direction to avoid being snagged by floating debris.

Gabion Revetments

Gabion revetments are commonly used to protect eroding streambanks, landslips, and bridge abutments. This type of structure is expensive, but long lasting. Gabion revetments require less stone than do riprapped banks.

Numerous designs are available for construction of revetments from gabion manufacturers.

Other Revetments

Other revetments include reinforced earth walls, wood, metal and concrete bulkheads, cellular concrete grids, concrete mattresses, Enviroblox, sand-filled tubes, used tires, porous concrete, bituminous paving, asphalt mattresses, concrete slabs, and monolithic concrete. Many of these have adverse effects on fish and are not visually pleasing (Schnick 1972).

Woody Vegetation Removal

Trees and woody brush (like alders) can excessively shade a stream and limit food production. Fish sheltering characteristics of natural channels are enhanced by the right type of vegetation, mainly the low-stream edge plants that drape in the water. These and beneficial aquatic plants cannot grow well in dense tree shade and tall brush. Overshadowing may be an acute hazard along small (less than 20 feet wide) streams. Removing bank brush increases sunlight energy to the stream, which encourages aquatic plant growth. Hunt (1979) warns that brush should not be removed along streams with temperatures at the upper limits of 70 °F for trout. Brushing has resulted in narrowing and deepening of the stream channel in Wisconsin and Michigan.

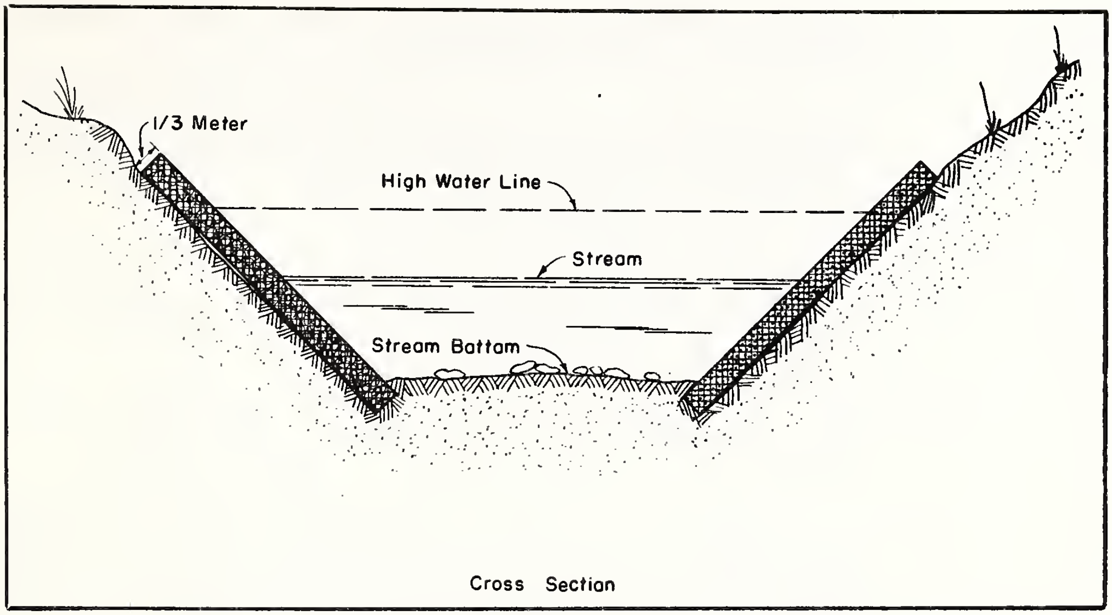


Figure 1-39. Gabion mats.

REGULATING DAMS

Streamflow Maintenance Dams

Many drains dry up before fall when the runoff from melting snow and the groundwater output is not sufficient to supply satisfactory streamflows during the driest months. Augmentation of low summer flow may be an effective approach to habitat enhancement for trout (Hall and Baker 1982). In other streams, water temperatures rise beyond desirable limits, or spawning beds dry out before fish fry emerge. Often there is high fish mortality resulting from stranding in streambeds. In such areas, fishermen get a mediocre return for their efforts. Where feasible, such deficiencies should be corrected by constructing streamflow maintenance dams. Where water can be stored behind such structures during the spring runoff period in sufficient quantity to allow adequate flows during the summer months, the deficiencies can be corrected.

Streamflow maintenance dams also can serve in some areas to correct situations where normal streamflows have been preempted by irrigation, power diversions, or impoundments.

The following factors should be considered in determining the need for a streamflow maintenance dam and the suitability of construction sites.

(1) Sites must have sufficient storage capacity to keep the outlet stream flowing during the dry months. Sometimes this

deficiency can be overcome by constructing two or more dams tributary to the same stream.

(2) Desirable streamflow maintenance project sites commonly are inaccessible to motor transportation making material costs high. Sites should be able to store an adequate amount of water at a reasonable cost.

(3) The benefiting stream should have physical characteristics capable of supporting fish in reasonable quantity. A stream with medium steep gradients and without pools may not justify development.

(4) Downstream limits on carrying capacity in winter should not negate benefits gained during the summer and fall.

(5) If a headwater lake with an existing fishery is proposed for development, any possible reduction in the fish-producing capacity of the lake should be weighed against the benefits expected from increased flows in the outlet stream. Also, the values of increased waterflows during critical periods should be weighed against the potential damage to the downstream fishery resulting from release of warmer impounded waters.

(6) Priority should be given to those streamflow maintenance dam projects that are characterized by low storage cost, benefit to considerable stream mileage, and having stream spawning areas accessible from the lake.

(7) The most satisfactory structures for streamflow maintenance dams are native materials that harmonize with the setting.

Power, Irrigation, and Municipal Dams

In the past, public and private agencies sometimes have been allowed to divert or impound streamflows without adequate water release for fish in the stream below. With power projects under FERC regulation, relicensing is normally required at the end of each 50-year period to allow correction of instream flow inadequacies, and such production must not be overlooked. Where existing projects are not subject to relicensing, agencies sometimes are willing to renegotiate such matters. Streamflow release schedules and reservoir level controls should be developed cooperatively with State fish and game agencies, the National Marine Fisheries Service, and the U.S. Fish and Wildlife Service.

Instream Flow Regulation

Instream flow regulation is probably the most important prerequisite for the maintenance and preservation of aquatic and riparian habitats. Maintenance flows are designed to maintain a satisfactory combination of spawning, resting, and food-production areas for fish. Although frequently receiving less emphasis, instream flows have a significant effect on groundwater recharge and the riparian plant community. Reduction in both surface water and

groundwater will influence riparian vegetation, and can result in the complete destruction of a riparian community (Riparian Habitat Committee 1982).

State water laws and administrative regulations frequently place limitations on water allocations for aquatic and wildlife resources. In many States, instream flow reservations for maintenance of fish and wildlife values cannot be appropriated or reserved. Another major constraint on reserving instream flows for aquatic and riparian preservation is the perceived resulting loss of reservoir storage capacity and water yield for irrigation, power production, domestic and industrial consumption. An excellent summary of strategies for achieving minimum instream flows has been developed by Solomon and Horak (1979).

WATER QUALITY

Temperature

No single factor affects the development and growth of fish as much as water temperature (Piper et al. 1982). Metabolic rates of fish increase rapidly as temperature increases. Many biological processes such as development, spawning, and egg hatching are geared to annual temperature changes in the natural environment. Although optimum temperatures vary with species (Table 1-8), warm-water fish generally do best at summer water temperatures of 80 to 85 °F and winter temperatures of 40 to 60 °F. Cold-water species prefer summer water temperatures of 50 to 70 °F. Winter temperatures for cold-water species should remain less than 58 °F. Successful spawning of salmonids has occurred in water temperatures ranging from 35 to 69 °F (Table 1-9) (Reiser and Bjornn 1979).

Temperature control is very important. Within limits, water temperature can be manipulated by adding or subtracting riparian vegetation. Although most critical problems occur with waters becoming too warm, some western streams are too cold. Generally, planting shade cover will reduce stream temperatures; removing shade generally increases temperatures. However, land managers should give serious consideration to all factors affected by shade removal. For instance, increasing the temperature a few degrees in several small tributaries may raise the temperature of a larger receiving stream to the point where it becomes intolerable to some fish species. Clearcutting of timber in a major portion of a drainage will usually raise the water temperature and, at the same time, increase peak streamflows during critical periods.

Regulating reservoir outflow is another method of controlling stream temperatures. Most deep-water reservoirs exhibit thermal stratification during certain periods of the year. During summer stratification periods, warm water occurs at upper levels, and the layers decrease in temperature with increasing depth. By using multilevel outlets, water can be drawn for downstream releases at desired temperatures.

Table 1-8. Water temperature requirements for fish species.

Species	Spawning Frequency	Temperature (°F) Range	Optimum	Spawning	Eggs Per Pound of Fish
Chinook salmon	Once per life span	33-77	50-57	45-55	350
Coho salmon	Once per life span	33-77	48-58	45-55	400
Sockeye salmon	Once per life span	33-70	50-59	45-54	500
Atlantic salmon	Annual-Biennial	33-75	50-62	42-50	800
Rainbow trout	Annual	33-78	50-60	50-55	1,000
Brook trout	Annual	33-72	45-55	45-55	1,200
Brown trout	Annual	33-78	48-60	48-55	1,000
Lake trout	Annual	33-70	42-58	48-52	800
Northern pike	Annual	33-80	40-65	40-48	9,100
Muskellunge	Annual	33-80	45-65	45-55	7,000
Walleye	Annual	33-80	45-70	48-55	25,000
Striped bass	Annual	35-90	55-75	55-71	100,000
Channel catfish	Annual	33-95	70-85	72-82	3,750
Flathead catfish	Annual	33-95	65-80	70-80	2,000
Largemouth bass	Annual	33-95	55-80	60-65	13,000
Smallmouth bass	Annual	33-90	50-70	58-62	8,000
Bluegill	Intermittent	33-95	55-80	65-80	50,000
Golden shiner	Intermittent	33-90	50-80	65-80	75,000
Goldfish	Intermittent	33-95	45-80	55-80	50,000
American shad	Annual	33-80	45-70	50-65	70,000
Common carp	Intermittent Semi-annually	33-95	55-80	55-80	60,000

Source: Piper et al. 1982

Table 1-9. Recommended temperatures for incubation of salmonid fish (°F).

Species	Incubation Temperature
Fall Chinook	41.0-57.9
Spring Chinook	41.0-57.9
Summer Chinook	41.0-57.9
Chum	39.9-55.9
Coho	39.9-55.9
Pink	39.9-55.9
Sockeye	39.9-55.9
Kokanee	---
Steelhead	---
Rainbow	---
Cutthroat	---
Brown	---

Source: Reiser and Bjornn 1979

Turbidity

Turbidity is a measure of the suspended solids present in water, usually expressed in parts per million (ppm). The ability of light to penetrate water has a pronounced effect on growth and survival of bottom fauna and flora that, in turn, affect fish growth and survival. Many fish species feed mainly by sight and are at a distinct disadvantage when confronted with highly turbid waters. Spawning migrations may be hindered by high turbidity.

Turbidity caused by inorganic sediments, such as colloidal clay, is extremely detrimental to fish production. Muddy water usually contains more than 2,000 ppm. Adult fish can withstand turbidities in excess of 100,000 ppm before mortality results (Piper et al. 1982). Destruction by sedimentation of spawning areas and reduction in bottom organisms are probably the most significant effects of turbidity and settleable solids in streams. For instance, studies show that there may be an average survival rate for fish under

1 year old of approximately 23 percent in clean, shallow gravel. Compare this with a survival of only 2 percent in areas in which riffle sedimentation is very heavy. In Oklahoma, the average total weight of fish in clear ponds was about 1.7 times that of those in ponds of intermediate turbidities and approximately 5.5 times greater than those in muddy ponds.

Another effect of suspended solids is the scouring of stream bottoms with abrasive materials, resulting in removal of algae, plants, and bottom food organisms.

There are as yet no set criteria to determine allowable turbidities. However, it is generally accepted that Secchi disk transparency should be 15 inches or greater. A Secchi disk is a circular plate approximately 8 inches in diameter and painted with opposing black and white quadrants. The transparency reading is determined by measuring the depth at which the disk disappears. Another accepted standard is that under conditions of brilliant sunlight at or near noon, 4 percent of the incident light (as measured by underwater photometry) should reach a depth of 6 feet.

Usually, good land management practices indirectly control turbidity for stream improvement. Protection or improvement of riparian vegetation along streamsides is especially important in this regard. Turbidities occurring as a result of land disturbance, during periods of low waterflow, are much more harmful than those during periods of high flows. During low flow conditions, deposition is rapid and concentration more probable.

Chemical Qualities

Numerous chemical elements and compounds are necessary for fish growth and survival. As with physical properties of water, the range of tolerance for chemical properties varies widely with species.

<u>Oxygen</u>

Oxygen requirements for fish vary considerably depending upon species, temperature, carbon dioxide levels, and other factors. As temperatures rise, oxygen requirements also increase. For salmonids in general, 6 ppm oxygen should be maintained for best production. Trout may require even higher oxygen levels, a minimum of 7.6 ppm oxygen at 58 °F for brook trout. In order to maintain good warm-water game-fish populations, oxygen concentrations should not fall below 5 ppm (Piper et al. 1982).

In addition to the absorption of oxygen directly from the atmosphere, bodies of water derive this element from photosynthesis of chlorophyll-bearing plants. Waters containing large amounts of plankton are usually supersaturated with oxygen during bright, sunny days, but may drop to critical levels on dark nights when photosynthesis is completely stopped and oxygen consumption

continues or oxygen escapes from the water. In waters in the North, this same effect is created for long time periods when ponds and lakes are covered with ice. Fish kills are not uncommon in these situations.

Carbon Dioxide

Carbon dioxide is one of the basic factors determining productivity of waters, since it is necessary in photosynthesis and for keeping minerals, such as calcium, in solution. Abrupt increases in carbon dioxide can result in fish kills even with ample oxygen. High carbon dioxide levels reduce the ability of fish to take up oxygen and to excrete carbon dioxide through the body membranes. Generally, waters supporting good fish populations have fewer than 5 ppm carbon dioxide. Carbon dioxide exceeding 20 ppm may be harmful to fish. It is doubtful that freshwater fish can live throughout the year in an average carbon dioxide content as high as 12 ppm (Piper et al. 1982).

pH

pH is a measure of the acid intensity in water as indicated by hydrogen ion concentration. A scale ranging from 0 to 14 simplifies the expression of this relationship, with pH values below 7 representing acid reactions, values above 7 representing alkaline reactions, and 7 representing neutrality. As pH approaches 0, acidity increases, and as values approach 14, alkalinity increases. pH values below 5 and above 9 seriously affect the ability of some fish to extract oxygen from water. The pH range for best fish production lies between 6.5 and 8.5, and fishery experts agree that optimum production is maintained at a slightly alkaline pH. Fish have less tolerance to pH extremes at higher temperatures. Liming has been used to attempt to raise low pH, and treatment with a combination of sulfur, manure, and gypsum may be effective in reducing pH (Piper et al. 1982).

Alkalinity

Alkalinity is a measure of the hydroxyl, carbonate, and bicarbonate ions in water. It is normally expressed in ppm of calcium carbonate ($CaCO_3$), and in most running water is in the form of bicarbonates (primarily as calcium bicarbonate). These bicarbonates perform two important functions. They serve as a "buffer" to stabilize pH levels by combining with strong acids or bases to form harmless compounds. They also provide a source of carbon dioxide for photosynthesis in plants. Waters low in alkalinity are subject to sudden changes in pH resulting in fish kills in extreme cases. Table 1-10 shows the relation between total alkalinity and fish productivity.

Table 1-10. Alkalinity and fish productivity.

Total Alkalinity (ppm)	Classification	Fish Productivity
0-20	Very soft	Low
21-40	Soft	Low-medium
41-90	Medium-hard	Medium-high
91 or more	Hard	High

The California State Water Quality Control Board gives 100 to 120 ppm total alkalinity as optimum for support of diversified aquatic life. Fish grow well over a wide range of alkalinities, but values of 120 to 400 ppm are optimum (Piper et al. 1982). The addition of lime in certain lakes increases alkalinity and productivity. For example, in Michigan, the addition of lime to one lake increased alkalinity from 6 to 15 ppm and improved biological productivity (McKee 1962).

Total Hardness

Total hardness is the total amount of alkaline earth constituents (Ca and Mg cations) present in the water. In the United States, it is expressed in ppm of calcium carbonate ($CaCO_3$). Many biologists consider total hardness the best single indicator of productivity since it indicates the amount of nutrients available for plant and animal growth. Values of 120 to 400 ppm are optimum.

In addition to their value as nutrients, the nontoxic earth metals, such as calcium, magnesium, and potassium, have a neutralizing effect on the salts of such toxic metals as copper, silver, zinc, lead, and cadmium (McKee 1963).

Some studies show that temperature stress is less in hard water than in soft water. Although productivity standards have not been set for water hardness, it is safe to say that hard water is generally more productive than soft water. As a guideline, water with a total hardness of less than 10 to 15 ppm should be classified as soft.

Total Dissolved Solids and Electrolytes

Measurement of the total dissolved solids and electrolytes in water with a conductivity meter is another method of determining productivity. As in total hardness, the richer a body of water in these

dissolved substances, the greater its biological productivity. Conductivity readings converted to ppm total dissolved solids will be higher than total hardness readings since acids, bases, salts, and any other material that conducts electricity will affect the readings. The actual amount of dissolved solids is not particularly important for most freshwater fish within the range of 1 to 1,000 ppm. Rainbow trout can tolerate 30,000 and channel catfish 11,000 ppm dissolved solids. However, rapid changes in concentrations are stressful to fish (Piper et al. 1982). Ninety-five percent of the inland water in the United States has under 400 ppm dissolved solids.

Pollution Control

Water pollution is the specific impairment of water quality by agriculture, domestic, or industrial wastes (including thermal and atomic wastes) to such a degree that it adversely affects the beneficial use of water, but does not necessarily create an actual hazard to public health. The Federal Water Pollution Control Act Amendments of 1972 (PL 92-500) established national policies regarding the maintenance and restoration of the integrity of the Nation's waters and authorized States to establish water quality standards and pollution discharge limitations applicable to all waters within the State upon approval of the Environmental Protection Agency.

RESTORING AND MAINTAINING FISH POPULATIONS IN STREAMS

Within fish communities, competition (both interspecific and intraspecific) for food and space plays a major role in defining the character of the fishery. Combined with the effects of predation and reproduction, competition influences fish growth rates and numerical composition by species and year classes (Bennett 1970). Under ideal conditions, the success of these forces interact to produce a fish community that is in a healthy, balanced condition, and the relative abundance of predator and prey remains fairly constant. However, ideal conditions are rare when human influences are present. The primary objective of fish population manipulation methods is to restore or maintain a balanced fish population.

Generally, the manipulation of fish populations is a responsibility of the State fish and game agency since direct management of a species is involved. The Forest Service role is usually to ensure proper coordination with other uses of the National Forests.

Fishing Regulations

Recreational angling exerts a tremendous influence on the fish community structure. If angling pressure is excessive, the integrity of the fishery may be jeopardized. To prevent overexploitation of fishery resources, governmental regulations have been instituted. Such regulations control the method of angler harvest, the rate of angler harvest, the size of fish that can be creeled, and the geographic boundaries of angling activity.

Where the threat of an overabundance of prey fish occurs, it is usually desirable to maintain predator populations with an abundance of large individuals. Minimum- or slot-size limits may promote such a population structure (Johnson and Anderson 1974). Relaxing regulations encourages the opposite effect. The effectiveness of regulations in meeting fish management goals is usually limited to reducing harvest. Several authors have discussed the theory of harvest regulation as it relates to common river game fish (Bennett 1970, Cooper 1980, Funk 1972, Kendall 1978, Noble 1980).

Mechanical Control--Netting and Electroshocking

Mechanical removal is typically characterized by some method of netting, but electroshocking methods also are used (Snow 1967). Types of nets that may be used include trawls, gill nets, hoop nets, trammel nets, trap nets, and seines (Hacker 1975, Sullivan 1967, Priegel 1971, Miller et al. 1969, Churchill 1949, and Jester 1971).

Mechanical removal has met with mixed success. Depending on the type of gear used, mechanical removal of fish may produce adverse effects on nontarget populations. Gill nets often severely injure or kill fish caught and are generally size selective. Species selectivity depends on the time of fishing, mesh size, and placement of the nets. However, habitats used by different species overlap, and nontarget fish are often caught. Mechanical removal of fish is a time-consuming, costly procedure. Costs are primarily associated with labor and equipment and are similar to costs for net-type sampling techniques.

Mechanical rough fish removal projects can be beneficial under certain circumstances (Miller et al. 1969, Priegel 1971). Direct damage to nontarget species can be insignificant when conditions are controlled. Circumstances that justify mechanical control arise when angling pressures on the fishery resource are high. The benefits to sport fish populations from the large-scale removal of dominant rough fish species will often outweigh any direct damage to nontarget populations. Commercial fishing is preferred whenever feasible because marketing of the captured fish reduces agency operation costs. A problem often encountered by commercial fishermen is that of unprofitability as fish removal rates approach effective fish management levels and catch rates decline (Hacker 1975, Priegel 1971).

If in doubt as to the efficacy of mechanical removal techniques for your application, habitat modification techniques should be considered. Techniques that result in speeding up the current or cooling the water may be ultimately more effective and long-lasting than mechanical removal.

Chemical Control Piscicides are routinely used in fishery management for the control of pest species, as well as for management of out-of-balance fish populations.

Fish Toxicants

Although more than 40 substances have been used as fish toxicants (Lennon 1971, Lennon et al. 1970), only 4 are currently registered for use as piscicides by the U.S. Environmental Protection Agency (EPA) (Meyer et al. 1976, Schnick et al. 1979): antimycin, rotenone, Bayer 73, and TFM (3-trifluoromethyl-4-nitrophenol). Bayer 73 and TFM are used only as lampricides in both Canada and the United States in lotic and lentic waters of the Great Lakes system (Schnick 1972, Hamilton 1974, Gilderhus and Johnson 1980). The compounds are used to kill larval sea lampreys and may be applied only by governmental agencies.

Rotenone and antimycin can be used effectively to manipulate fish populations (Table 1-11). Selective thinning, as well as complete reclamation of lentic and lotic systems, has been done using these substances (Hacker 1971, Hooper and Crance 1960, Johnson 1975). Libey and Holland (1980) described a method for selectively thinning larval bluegills by making periodic applications of rotenone at low concentrations. Greenbank (1941) demonstrated that rotenone could be used selectively to kill warm-water species and to spare salmonids in a thermally stratified lake. Various formulations of antimycin can be used to produce similar results.

Fintrol-5 and Fintrol-15 (antimycin) are formulated to release the toxicant in the first 5 and 15 feet of water, respectively (Lennon et al. 1970). A sand grain carrier releases the toxicant as it sinks through the water column.

The recommended concentrations of rotenone and antimycin are generally safe for nontarget organisms. Although most fish toxicants are also toxic to aquatic invertebrates, the effect is temporary; usually the populations rapidly rebuild to pretreatment levels (Lennon 1971, Schnick 1974a, 1974b, 1972).

An advantage of rotenone, not directly related to fishery resource manipulation, is its usefulness in fish population sampling during survey work (Crondell et al. 1976, Holder 1975, Masnik et al. 1978, Provine 1976, Timmons et al. 1978). The principal advantage of antimycin, in comparison with rotenone, is that its presence is not sensed by fish (Lennon et al. 1970). Because antimycin cannot be detected by fish and is not as temperature sensitive as rotenone, it is the best substance for stream reclamation and other projects where low temperatures or avoidance by fish may result in unwanted survival.

Fish toxicants are generally expensive. The cost of antimycin in April 1980 was $85 per unit. An application rate of 10 ppb then

Table 1-11. Registered fish toxicant information.

Antimycin	
Alternative name:	Fintrol-5, Fintrol-15, and Fintrol Concentrate.
Chemical Formula:	$C_{28}H_{40}N_2O_9$
Formulation:	Controlled-release coating on sand grains and as water-soluable liquid.
Primary use:	Registered fish toxicant in United States and Canada.
Secondary use:	Fungicide; miticide.
Safety hazard:	May cause conjunctivitis; protect eyes with safety glasses.
Persistence:	Nonpersistent in environment.
Rotenone	
Alternative name:	Noxfish, Pro-Noxfish, Nusyn-Noxfish, Chem-fish Regular, Chem-fish Special, Fish-Tox, Derris, Cube, Derrin, Nicouline, Tubatoxin, Timbo Powder.
Chemical Formula:	$C_{23}H_{22}O_6$
Formulation:	Liquid, synergized liquid, and powdered plant roots.
Primary use:	Insecticide.
Secondary use:	Registered fish toxicant in United States and Canada.
Mode of action:	Inhibitor of cellular respiration.
Safety Hazard:	Inhalation of powder can cause headaches, sore throats and other cold symptoms, and sores on mucous membranes; contact can cause eye irritation and skin rash. Protective clothing is advised when using powdered root. Use of wettable powder or liquid formulations reduces risk to safety and health.
Persistence:	Seldom persists in environment longer than 2 weeks; persists longer in very soft water.

Source: Lennon et al. 1970

cost \$21.78 per acre-foot of water. The two rotenone formulations, Nusyn-Noxfish and Noxfish, cost \$15.20 per gallon and \$21.70 per gallon, respectively. At an application rate of 2 ppm, Nusyn-Noxfish would cost \$10.03 per acre-foot and Noxfish, \$14.32.

Reviews of the current literature on fish toxicants are given by Hamilton (1974), Lennon (1970), Lennon et al. (1970), and Schnick (1972, 1974a, 1974b). Buchanan et al. (1974), Headrick et al. (1975), and Spitler (1970) also review the effectiveness of chemical treatment projects.

Reclamation Using Fish Toxicants

Total reclamation involves a complete kill of the existing fish population followed by a restocking of desirable species. A number of authors have prepared methodologies for reclamation of streams using fish toxicants. The steps outlined below draw on the work of Fernholz and Slifer (1967) in Wisconsin soft-water trout streams, McCoy and Ratledge (1967) in North Carolina mountain trout streams, and Lennon et al. (1970), as appropriate:

(1) In preparation for the environmental assessment, conduct a biological survey to determine the need for a reclamation project. An adequate assessment of fish populations in the project area must be done.

(2) Develop a public involvement program to win general consent for the project.

(3) As part of the environmental assessment, obtain written consent from riparian landowners, sportsmen clubs, civic groups, water regulatory agencies, and the public service commission as necessary.

(4) Set a tentative date for the project.

(5) Prepare an outline map of the project area, including all access points, streams, tributaries, backwaters, and toxicant stations.

(6) Establish stations for application of the toxicant about 1 mile apart.

(7) Measure volume of stream flow at each station and the rate of longitudinal mixing.

(8) Establish a benchmark at every fifth station at the time the flow measurements are made.

(9) Conduct salt-resistivity tests at each station, above and below the points of salt introduction. This is a determination of the linear relationship between specific conductance and known salt concentration at a constant temperature.

(10) Calculate toxicant requirements for each station from the reference table in the manual.

(11) Calculate the volume of any impoundments present and the amounts of toxicant needed to compensate for the additional volume in these areas.

(12) Perform toxicity studies to determine the concentration of toxicant and duration of exposure required to kill target species.

(13) Establish a detoxification station if required. If rotenone is used, detoxify the stream following treatment with potassium permanganate.

(14) Establish stations for cages of live test fish in treated area and untreated areas downstream.

(15) List manpower and equipment needs.

(16) Establish post-treatment survey procedures.

Procedures and techniques for stream reclamation are discussed by Slifer (1970), who covers such topics as the salt-conductivity relation, station location, toxicant selection, application rates, project timing, equipment, fish barriers, and detoxification. McCoy and Ratledge (1967) present an operation plan, including requirements for personnel, equipment, and supplies. Lennon et al. (1970) trace the evolution of principles and methods for the reclamation of streams and cite 31 references covering the period from 1954 to 1969.

Stocking

Stocking fish is one of the oldest methods of fish population manipulation. Stocked fish can help to reduce fishing pressure on native stocks and can be used to provide a fishery in waters where natural reproduction fails. Such fish also can provide diversity for anglers in an optimum sustained-yield fishery by giving them an opportunity to catch species that otherwise would not be available.

Stocking is far from being a cure-all. Bennett (1970) stated that accumulated evidence suggested that successful stocking is limited to the following situations:

(1) Interim stocking of trout large enough to be caught immediately or barren lakes such as the salmon-rearing program in Alaska.

(2) Stocking in newly constructed and filled artificial lakes and reservoirs.

(3) Stocking in reclaimed or renovated lakes or streams after the indigenous or stocked-fish population has been removed.

(4) Introducing a new species to improve the ecosystem, either for sport fishing or as a "fill-in" for the food chain. Such an introduction should be preceded by a partial poisoning of the present fish population to ensure that competition for food and space is reduced before the new fish are released.

(5) Stocking where conditions for growth are favorable, but reproduction is uncertain (for example, when channel catfish are released in ponds containing mixed populations of fish) or subject to predictable failure (as in shallow lakes subject to complete winterkill).

(6) Stocking in habitats newly accessed by fish laddering projects. This is done to hasten the establishment of desired species and their use of the habitat upstream from the fishway.

Some notable fishery management successes and failures have been associated with the stocking of exotics. Introductions of exotics must be preceded by research and evaluation to determine the ecological, social, and economic benefits and costs (Anderson 1975). An environmental assessment must be prepared as part of the evaluation process. Notable successes include the establishment of coho salmon and chinook salmon in the Great Lakes, striped bass and its hybrids (striped bass with white bass) and treadfin shad in southern reservoirs, and brown trout throughout the United States. The most notable disaster has been the introduction of the common carp.

Many descriptions of stocking methodologies have been published. It is apparent that no standard methodology has been established and that many variables influence procedures. Fry, fingerlings, and adults have all been used, and the rates at which fry and fingerlings are stocked in large systems often depends on availability. Moreover, it often is difficult to estimate angler catches of edible-size fish resulting from plantings of fry in streams where the species stocked are already established. Fingerlings of different sizes can be used, but survival often depends on the abundance of food and predators (Klingbiel 1971, Paxton and Day 1979).

Barriers

Natural or manmade barriers are effective in blocking upstream fish migrations. When headwater streams are chemically treated to control undesirable fish, barriers are usually needed to prevent reinfestation from below. As with chemical control, barrier installation will normally be done by State agencies. The Forest Service has built trickle dams (rock-filled logcribs) across outlets of reclaimed lakes to deny ingress from downstream. In any case, installation will require State concurrence in design, location, and purpose.

Falls are the most commonly encountered natural barriers. An artificial barrier is difficult to design and is often expensive to construct and maintain, particularly on large streams or those subject to extreme fluctuations in flow.

Several problems that planners should be aware of can be created by the installation of barriers. When barrier dams are used to block upstream passage of fish, a small impoundment is formed that may cause loss of habitat as a result of reduced flow and increased siltation. Unfavorable high-water temperatures may result when barriers are built on small, cold, or cool-water streams. Lastly, barriers may prove detrimental if desirable fish species are denied access to spawning areas.

FERTILIZING AND LIMING STREAMS

Fertilizing Streams

Productivity of streams is directly related to productivity of the watershed. Experimental enrichment of streams has been achieved (Warren et al. 1964, Huntsman 1948); for example, Warren et al. (1964) increased the production of cutthroat trout sevenfold by adding sucrose to a stream. The chief deterrent to fertilization of even a small stream is the high cost. Even a very small stream requires 1-1/2 tons a year of fertilizer to produce any effect for a short distance below the point of application (Everhart and Youngs 1981). For this reason, stream fertilization currently is not a practical fish management procedure.

Acidified Streams and Liming

Increased acidification of streams and lakes in many areas of the United States has been caused by acid precipitation and mine drainage. Susceptibility to acidification may vary considerably among streams within an area. Factors such as hydrology, watershed order, bedrock geology, and soil type may affect the susceptibility of a stream to acidification. Surface waters with alkalinity of 10 mg/l or less of $CaCO_3$ are considered sensitive to acidification, and those with 10-15 mg/l of $CaCO_3$ are considered potentially sensitive.

Neutralization of surface waters is a feasible but not simple technique. Principal problems involve logistics and cost of base dispersal, longevity of treatment, and maintenance of water quality during "acid pulses" associated with snowmelt and major rain storms (Baker 1984). Corrective strategies involve direct additions of limestone ($CaCO_3$), lime (CaO and $Ca(OH)_2$), soda ash ($NaCO_3$), olivine ($(Mg, Fe)_2 SiO_4$), fly ash, and industrial slags which can be used as neutralizing agents (Fraser and Britt 1982). Totally successful liming techniques for running waters have yet to be developed (Hasselrot and Hultberg 1984), although the rotary drum method using limestone aggregate described in a following section is effective but costly to maintain.

Another management alternative is repeated stocking with hatchery fish. This practice replenishes fish populations that would otherwise decline. Neutralization (liming) and stocking provide only temporary results. Control of fossil-fuel emissions and acid mine drainage, enforcement of present emission standards, and research address the source of the problem.

Consider using the following techniques if the value of the fishery resource outweighs the continuing and relatively high cost of liming. For instance, a valuable trout stream close to a metropolitan area where few streams exist, and otherwise capable of supporting a productive population, is a likely candidate for neutralization treatment. The West Virginia Department of Natural Resources has been active in liming research not only because of the extent of the acid mine runoff problem but also because of the contribution their trout streams make to drawing fishermen's dollars from nearby cities.

Watershed and Streambed Limestone

Direct application of limestone aggregate to the watershed (Anderson et al. 1982) or streambed (Zurbuch 1984) is effective in temporarily raising stream pH. Through time, however, the neutralizing effect of the limestone aggregate diminishes to the point where it has no significant effect on streamwater pH. Streambed application of limestone has potential value and should be researched further.

Continuous Feeders

As a result of maintenance and mechanical problems, varied methods of mechanically feeding hydrated lime or aglime have not been fully successful. The Forest Service tested a mechanical system in 1971-72 and concluded the system was not applicable. Rosseland and Skogheim (1984) found the best way to ensure a proportional dosage of neutralizing material to acid running water is through the continual application of a base. Several systems for dosing with finely powdered limestone have been constructed in Sweden (Anon 1981), but these systems require frequent inspection and maintenance.

Rotary Drum

A rotary drum system has been developed by the West Virginia Department of Natural Resources. Their 25 years of experience in neutralization of acidified streams led to the development of water-powered rotating drums containing limestone aggregate. Rotary drum systems have proven successful on West Virginia streams (Zurbuch 1984). The Forest Service installed a one-drum treatment on Bear Run Creek near Richwood, West Virginia, and the pH was raised 1.0 to 1.5 units. This allowed the stocking of trout in the

stream. However, maintenance of the drums by handloading aggregate may be expensive and impractical for many situations.

Self-Feeding Rotary Drum

The West Virginia Department of Natural Resources has developed a self-feeding rotary drum. More than 36 tons of 1-1/2-inch limestone was consumed during one 3-month test period. The system is designed for: self feeding, production of up to 12 pounds per hour of limestone fines, unattended operation with minimum maintenance, and bin storage of a week's supply of limestone (9 to 10 tons) (Zurbuch 1984). The construction cost of rotary drum facilities is about $50,000 per drum (1983 dollars).

Chapter 2
Lake Habitat Improvement

IMPOUNDMENTS

Construction of small impoundments expressly for providing additional game-fish habitat has been very successful on National Forest lands in some Regions.

The quality of habitat in fishery impoundments largely depends on how stable water levels are over shallow areas when most of the fishfood is produced. An increase in depth and surface area may increase productivity and eliminate or reduce winter-kill problems. Building small dams at the outlets of natural lakes to increase their depth and surface area has been very successful, especially in small lakes that are otherwise incapable of maintaining a game-fish population. Dams at the outlets of mountain lakes that release water during periods of low stream flow are a popular type of impoundment on the west coast (Calhoun 1966).

Planning Impoundments

Because many variables are involved, plans for new impoundments or for lake-level improvement projects must be individually analyzed.

The Soil Conservation Service, the Fish and Wildlife Service, the Corps of Engineers, State fish and game agencies, and Forest Service engineers can provide assistance during early stages of each feasibility study. Such projects may be cooperatively financed and carried out with State fish and game agencies.

When planning water impoundments or lake-level improvement projects, the following items should be considered:

(1) A record should be searched to determine water rights and prior uses that would conflict with the project's purposes or with application of the reservation principle. This investigation should be given first priority in preliminary studies, because there is little use for further planning unless sufficient water is available to fill the impoundment and maintain desired water levels.

(2) A multiple-use survey and impact report is needed to ensure coordination with other resources and land uses.

(3) Coordination with other Federal agencies and the State fish and game agency is essential, not only to encourage participation in the project but also to avoid conflicts with State management plans. Such coordination and cooperation will help ensure maximum public benefits from the fishery resources produced.

(4) In evaluating the physical features of the site, the following points should be taken into account:

(a) A site that readily lends itself to dam and spillway construction is necessary to avoid excessive costs.

(b) Topography of the basin must allow for impoundment of enough water to justify the cost of the dam, and its configuration must promote good biological conditions after impoundment.

(c) A maximum lake depth of 30 to 40 feet is advisable. Productivity is greater in shallow lakes.

(d) While the water supply must be sufficient to prevent winter-kill, a small flow is desirable for productivity. Sites that involve flooding of substantial sections of quality trout stream habitat should have low priority.

(e) Sites at lower mountain elevations yield greater benefits through higher productivity, easier public access, and longer seasons of use.

(f) Conditions on the watershed are extremely important. Ackerman and Corinth (1962) have developed an empirical equation for predicting the annual rate of impoundment sediment deposition. Anticipated sediment deposition in the reservoir basin should be low.

(g) An analysis of site soils should be made to determine biological fertility and the absence of toxic elements such as selenium. Soil types should be evaluated at the dam site to determine their suitability for construction requirements.

(5) An evaluation of biological factors should be made to determine whether threat of infestation from unwanted fish species exists and, if so, the probability of controlling them. Also, an evaluation should be made to determine whether excessive growth of aquatic plants poses a threat and the probability of controlling such growth.

(6) The quality of the water should be checked against Federal and State water quality standards for possible detrimental effects the impoundment may have on the characteristics of downstream water, especially temperature. Standards for game-fish species to be managed also should be maintained, both in and below the impoundment.

(7) A fishery impoundment should be planned, designed, constructed, operated, and maintained to ensure that it fulfills its intended purpose with minimal damage to land and other resources. Engineering standards and procedures should be used as guides to meet this objective. In addition, Forest Service project plans should be prepared by either Forest or Regional engineers, or by contracting with a consulting engineering firm.

The elements of a management plan should be considered, including species and numbers of fish to be stocked, boating and other recreation uses, zoning, special fishing regulations, spawning facilities and protection, access problems, public-use facilities, and other considerations. Coordination with other Forest Service functions and other Federal and State agencies also is essential to the management and planning process.

Consequences of Impoundments

In planning stream impoundments, it is important to consider the profound consequences of impoundment on rivers or streams. Changes occur in the chemical and physical properties of rivers, and changes in endemic biotic communities reflect the environmental changes (Ward and Stanford 1979).

Plans also must consider the complementarity of environmental effects in the river reaches above and below a dam. Some examples of complementary effects include sedimentation above a dam, which leads to erosion below; the retention of heat in an impoundment, which cools the water downstream; and a decrease in the annual variation of water level below a dam, which is associated with an increased annual fluctuation above it, and vice versa (Baxter and Glaude 1980). The interdependence of water level and flow fluctuations above and below dams makes it difficult to manage both the impoundments and the tailwaters for the maximum benefit of the fisheries in the two areas.

WATER LEVELS

Controlling the water levels in lakes and impoundments is essential to adequate fishery management and requires knowledge of basin and water quality characteristics, fish species and population composition, management objectives and possibilities, climate, and other water uses. Maintaining the water levels required for fish production in a body of water is of primary importance, whereas the flexibility to manipulate water levels for various fishery purposes is usually of secondary importance. Competing uses for impounded water often have led to the decline or elimination of endemic fish populations (Orsborn and Allman 1976). Waters impounded primarily for power, irrigation, or domestic supply ideally should be managed or manipulated to protect or enhance fishery resources through permit stipulations.

Controlling Discharge

Controlling discharge from lakes or impoundments is the most efficient way to manage water levels. In cases where the stored water is principally allocated to fisheries, the size of the dam as it relates to the basin's hydrography is the main controlling factor. In the case of existing lakes (natural or impounded), it often is feasible to increase the dam's height (and length, if necessary). If minor reconstruction is required, adequate discharge control structures should be included in the design. Where it is not feasible to alter the dam structure, another possibility is to install discharge controls or redesign spillways.

Maintaining Instream Flow Requirements

Instream flow requirements for fish, wildlife, recreation, and other uses are now recognized in many places as legitimate uses under water law (Lamb 1977). Objective, scientific methodologies for determining instream flow requirements necessary for fish are being or have been developed so that appropriate allocations can be made for the management of reservoir level and river flow (U.S. Fish and Wildlife Service Instream Flow Group). While balancing the several requirements for multiple uses is usually the answer, this often leaves little flexibility for controlling fishery water levels. Following are the basic biological objectives of maintaining instream flow:

(1) Maintaining adequate flow for fish passage.

(2) Maintaining adequate flow over spawning, incubation, and nursery areas, as well as other shoreline food-producing areas.

(3) Providing sufficient "living room" and water quality.

(4) Ensuring adequate harvest possibilities.

Manipulating Water Levels

Water retention time and the drawdown zone and time are the main factors to consider when managing reservoir water levels and flows. Ploskey (1982) prepared an annotated bibliography concerning the effects of fluctuating water levels on physical and chemical characteristics, on algae and aquatic invertebrates, and on fish and fishing.

As a fishery management technique, water-level manipulation is a common, well-tested practice (Shields 1957). Water-level manipulations are particularly useful in applications such as the following:

(1) <u>Panfish Overpopulation</u>. In cases where panfish overpopulation and aquatic vegetation overabundance are problems, panfish often are stunted in size because of the inability of predators to find young panfish in the lush aquatic vegetation. In such situations, dropping the water level by 2 feet or more will strand small fish and force many of these juvenile forage fish out of the weed beds and into areas where the predator

fish can more effectively crop them. This simultaneously ensures faster growth in predator fish species and better control of panfish, with panfish growing to a more desirable size. The results may not be beneficial unless the drawdown reduces the surface area by more than 25 percent (Bennett 1970).

(2) <u>Game Fish Increases</u>. Studies have shown that populations of harvestable game fish have been increased by well-planned lake or reservoir drawdowns (Figure 2-1). Such water-level manipulation can increase bass reproduction by reducing bluegill numbers and their predation on bass nests.

(3) <u>Undesirable Fish Control</u>. Drawdowns can be used to control carp. Shortly after carp spawning is completed, the water level should be lowered enough to leave carp eggs stranded on the exposed shoreline. In the Northern United States, bullheads and mudminnows also can be controlled by a drawdown sufficient to expose the fish to winter-kill.

(4) <u>Weed Control</u>. Drawdowns also have been used with some success to control water weeds by exposing them to freezing weather (Bennett 1970).

(5) <u>Chemical Treatment Enhancement</u>. The manipulation of water levels can effectively reduce the cost of chemically controlling undesirable fish. If a lake can be drawn down to a fraction of its normal size, not only is less toxicant needed but its probability of effectiveness is increased. On the other hand, it has been found that allowing a small rise in water level to create marshy areas may increase the spawning success of predators such as the northern pike.

Although manipulating water-levels is beneficial when properly planned, it can be damaging if its limitations and dangers are not well understood. Drawdowns in reservoirs can reduce fishfood production and leave lake spawning areas high and dry. Rapid decreases in water levels, in particular those experienced in hydroelectric storage facilities, can adversely affect benthic fauna, fish spawning success, and riparian vegetation. Severe water-level fluctuations below hydroelectric facilities likewise constitute a hazard to endemic aquatic fauna and to the quality of riparian ecotone habitat. If the water level below a dam drops more than 6 inches in 6 hours, significant degradation of aquatic resources may occur (Tennant 1976).

In view of such potential problems, managing water levels to benefit fisheries should be done only with expert advice and in cooperation with the State fish and game agencies. If rapid and severe fluctuations of reservoir pools can be prevented, much potential damage to the fishery and reservoir habitat can be avoided.

Calendar Period	Level Manipulation	Habitat and Population Improvement Purposes
Jan 1 – Feb 28	Hold low	Provide spring runoff and flood capacity; allow weather to clean rocky shorelines of algae, silt.
Mar 1 – May 15	Increase gradually	Inundate vegetation and rocks for improved spawning; reduce walleye losses through dam outlets.
May 16 – Jun 30	Hold high	Maintain fish nursery habitat, decompose vegetation for nutrients and turbidity control.
Jul 1 – Jul 15	Decrease abruptly	Expose shorelines for revegetation; dessicate rough fish spawn.
Jul 16 – Sep 30	Hold low	Expose forage fish to predation; allow vegetation to mature.
Oct 1 – Nov 15	Increase gradually	Partially inundate vegetation for increased waterfowl food and cover.
Nov 16 – Dec 15	Hold intermediate	Maintain for maximum waterfowl use.
Dec 16 – Dec 31	Decrease gradually	Reduce ice and wave damage to vegetation; prepare for next season.

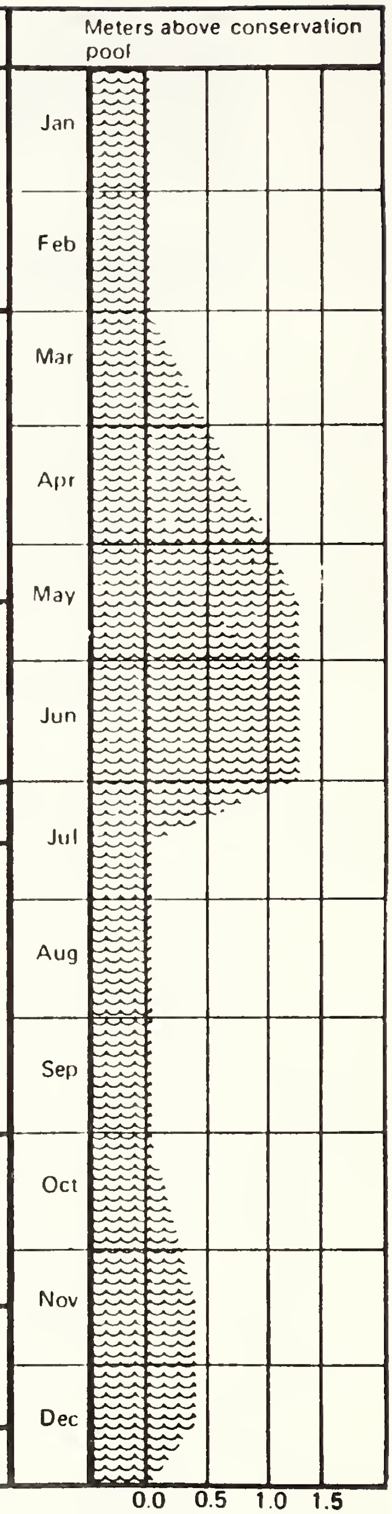


Figure 2-1. Typical water-level manipulation plan for a warm-water reservoir.

Source: Nelson et al. 1978

Maintaining Minimum Pools

Minimum pools are set for some impoundments to provide the amount of water considered essential for the survival of fish populations. Maintenance of a minimum reservoir pool reduces fish losses and thereby reduces the need for annual restocking to maintain adequate populations.

LAKE SPAWNING FACILITIES

Spawning behavior among fish species is very diverse. Some fish species build nests and provide parental care; others build nests and desert them after spawning; and still others build no nests, but broadcast sinking eggs over the bottom or buoyant eggs near the surface (Lagler et al. 1977). By taking into account these different types of egg-laying behavior, spawning structures have been developed that can increase the spawning success of a variety of fishes. If appropriate spawning habitat is limited, the construction of spawning structures can be an especially successful management measure. This section identifies the different techniques that have been used in attempts to naturally reproduce lake fish.

Spawning Boxes

One well-tested method that has been used for black bass and other centrarchids (Everhart and Youngs 1981) is to place shallow spawning boxes filled with gravel in hatchery ponds and lakes. Black bass prefer gravel-rubble substrate near cover (Coble 1975). In some lakes, larger areas of the lake bottom are artificially graveled, the intent being to facilitate the spawning of the nest-building fish species, particularly the black basses.

Spawning Reefs

Rock gravel spawning reefs may be constructed for any species of fish selected for spawning substrate. Gravel, stone size, and reef location are species-specific. With walleyes, for example, rock reefs can be developed as spawning habitat. A 2- to 10-fold increase in young walleyes was attributed to the construction of a spawning reef by Weber and Imler (1974); Johnson (1961) reported a 10-fold increase in walleye egg survival on constructed spawning reefs.

Placement of imported gravel in the mouth areas of inlet streams also has been used successfully to establish self-sustaining trout populations, especially in alpine or subalpine lakes, where spawning gravels are often lacking.

Experiments show that the following elements are essential to reef construction plans (Newburg 1975):

(1) To control sinking, the shoal must be placed on very firm substrate. Substrate may be prepared and stabilized by placing a 4- to 6-inch layer of 0.5- to 2-inch rock screening underneath a covering of the larger "spawning materials." An alternative method to rock screening that can produce the same results is to stretch a synthetic filter-cloth on the bottom before freezeup, with the spawning substrate placed on the ice and allowed to drop onto the filter-cloth during spring breakup.

(2) Materials should be a mixture of rock incorporating a bottom substrate stabilizer, if needed, 4 to 6 inches thick and made up of 0.5- to 1-inch rock; and a layer of spawning shoal rock, 12 inches deep, which should consist of a rock mixture in the following diameters: 10 percent of 3- to 5-inch rock, 50 percent of 5- to 7-inch rock, and 40 percent of 7- to 9-inch rock.

(3) Reconnaissance must be made of the immediate shoal area to determine whether there is sufficient material from the lake bed and erodible shoreline to present a serious siltation and detritus problem and also to determine the predominant direction and extent of shore drift. If there is a potential problem, one of the following solutions should be considered: relocating the shoal site, stabilizing the sediment source area, or constructing a jetty on the up-drift side of the shoal. Placing a temporary obstruction perpendicular to shore at the proposed site will cause sediments and detritus to build up on the up-drift side of the obstruction; however, periodic cleaning with stiff brooms and jets of water from a 1.5-inch pump can remove sediment, detritus, and periphyton from the rocks.

Artificial "Holes"

Catfish spawning success may be improved by installing spawning cavities constructed of various types of nonmetallic tile or pipe, or by using milk cans, nail kegs, hollow logs, or used-tire fish attractors (Bennett 1970, Prince et al. 1977, Wilbur 1974). If tile or pipes are used, one end should be plugged with 3 to 4 inches of concrete.

Pipes and drain or flue tiles have several advantages in new reservoirs, where they can be installed before filling the impoundment. Tiles are heavy, require no anchoring, and are durable. (If "seconds" are available, they are less expensive than first-quality tile.) Close one end of the tiles by filling them with 3 or 4 inches of concrete, then lay them horizontally in a small trench on the lake bottom, 3 to 5 feet below the conservation pool level. Lay them almost level, but with a slight upward tilting of the open ends to prevent trapping of air bubbles. On steeper bottoms, bury the tile so that about one-half of it sticks out like a hollow log. It is not necessary to close one end with concrete if the tile is pushed firmly into the lake bottom (Figure 2-2).

Spawning Platforms

Floating or suspended wooden platforms (a series of boards assembled with 3/8- to 1/2-inch spaces between them) can be used to facilitate the spawning of pimephalid minnows (fathead and bluntnose minnows), which attach their eggs to the bottom side of objects. Brush cuttings in shallow water, spawning slabs, and floating boards also serve as egg attachment sites for minnows.

Spawning Marshes Spawning marshes can be constructed to supplement natural spawning grounds for northern pike. Northern pike spawn in the weedy, shallow marshes along lakes and streams, and their reproduction often has been severely curtailed by shoreline filling operations for development or by marsh drainage. To combat this loss of northern pike spawning habitat, some of the North Central States have created artificial marshes, with spawning pike usually being captured and put in these shallow marshes or else attracted to the marsh by a flow of water from it. Actual spawning of pike takes place when water temperatures reach between 46 °F and 49 °F. Once adults have spawned, they are removed so that they will not cannibalize the fry, which usually can be seen within 3 to 6 weeks after spawning occurs. Where construction of such marshes is feasible, it can make an excellent cooperative project between the National Forests and local communities or fishing organizations. Some State-operated marshes are located on National Forests of the Great Lakes States.

Fago (1977) identified three qualities characterizing a marsh that can be properly developed and managed: (1) the marsh structures should facilitate complete drainage, (2) the marsh should be located near adequate water supplies, and (3) a vegetative cover of sedges and grasses should predominate. The water inlet structures should be screened to prevent the entry of predators and the outlet structures should allow surface drawdown. Fish-capture facilities may be incorporated into outlet structures as needed.

Nursery Ponds The separate-structure nursery pond is a strictly controlled, separate pond located adjacent to a receiving reservoir or stream that is usually connected with the reservoir or stream by a pipe, a channel, a gate system, and/or a canal (Keith 1969). Because runoff is usually the water source, the characteristics of the watershed are critically important, with pond size becoming a function of the drainage area incorporated. The pond itself must be filled at least once annually, but excessive nutrient flushing should be avoided. Moreover, if pollution and the immigration of unwanted fish are to be prevented, the entire watershed should be under managerial control.

Keith (1969) provides the following guidelines for site selection:

(1) Locate the facility where it can be drained directly into the receiving water.

(2) Provide a ratio of approximately 10:1 drainage area to pond surface area (based on hydrological characteristics in Arkansas) unless there is adequate spring or ground water flow.

(3) Provide adequate access to the site.

(4) Preferably, select a watershed that does not contain private ponds. If it does, complete control over the pond must be obtained.

(5) Design and construct nursery ponds to permit complete drainage. Poorly shaped bottoms develop potholes where fish readily become stranded when the pond is emptied.

Nursery Coves

The nursery cove barrier (Figure 2-3) isolates a cove (bay) from the remainder of an impoundment or lake where fish can be nurtured in a protected habitat before being released into the environment. The nursery cove technique was developed to provide a more economical alternative to nursery ponds (Smith 1976).

FISH ATTRACTORS IN LAKES

Because of the marked affinity fish have for cover, providing additional cover in lakes to attract fish can be an effective way to increase the fish harvest. Fish attractors provide cover that attracts forage species seeking shelter and predators seeking prey (Pierce and Hooper 1979, Prince et al. 1975, Wilbur and Crumpton 1974). They also are used frequently for escape cover by spawning centrarchids (Vogele and Rainwater 1975). In addition, by providing a stable substrate for the development of periphyton (Alfieri 1975, Pardue 1973, Prince et al. 1976) and colonization by macroinvertebrates, fish attractors provide a larger food base that can improve conditions and increase the production of fish species using the structures (Prince 1976, Swingle 1968).

To be effective, fish attractors must be placed in appropriate locations (Figure 2-4). The type of structure and the materials used will of course depend on the intended purpose of the structures and the availability of materials and labor. Materials used to construct freshwater attractors include used tires, brush trees, vitrified clay pipes, cement blocks, bricks, rubble, stake beds, clumps of plastic strips, automobile bodies, and old boats.

Tire Attractors

Tire shelters provide habitat for many fish species. Scrap tires have become one of the most popular materials for the construction of fish attractors (Prince et al. 1975, Stone et al. 1974, Wilbur and Crumpton 1974). Tires are often available in large quantities at no charge, are easy to manipulate, and are readily assembled into various configurations. Also, tires are inert: they do not decompose or leach harmful compounds (Stone et al. 1974, Tolley 1981). Structural designs have developed in which tires are used, but modifications and improvements may be desirable for particular applications (Figure 2-5) (Prince et al. 1977).

Brush Attractors

Brush also is used to construct fish attractors, with structures ranging from stacked brush frames, bundled brush-anchored trees, felled shoreline timbers, and brush combined with other materials. While green oak is preferred as a construction material, other green hardwoods or cedar may be substituted. Brush attractor

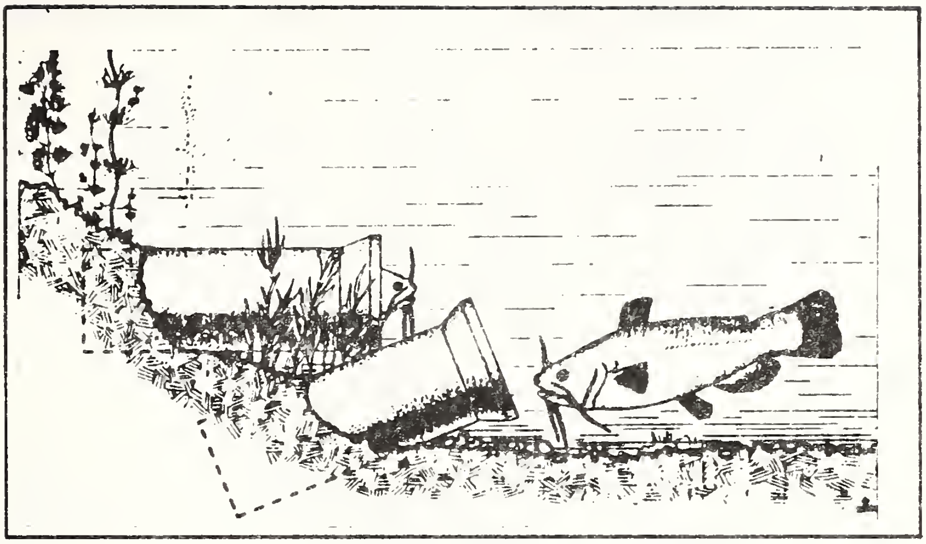


Figure 2-2. Catfish spawning shelters.

Source: U.S. Fish and Wildlife Service 1978

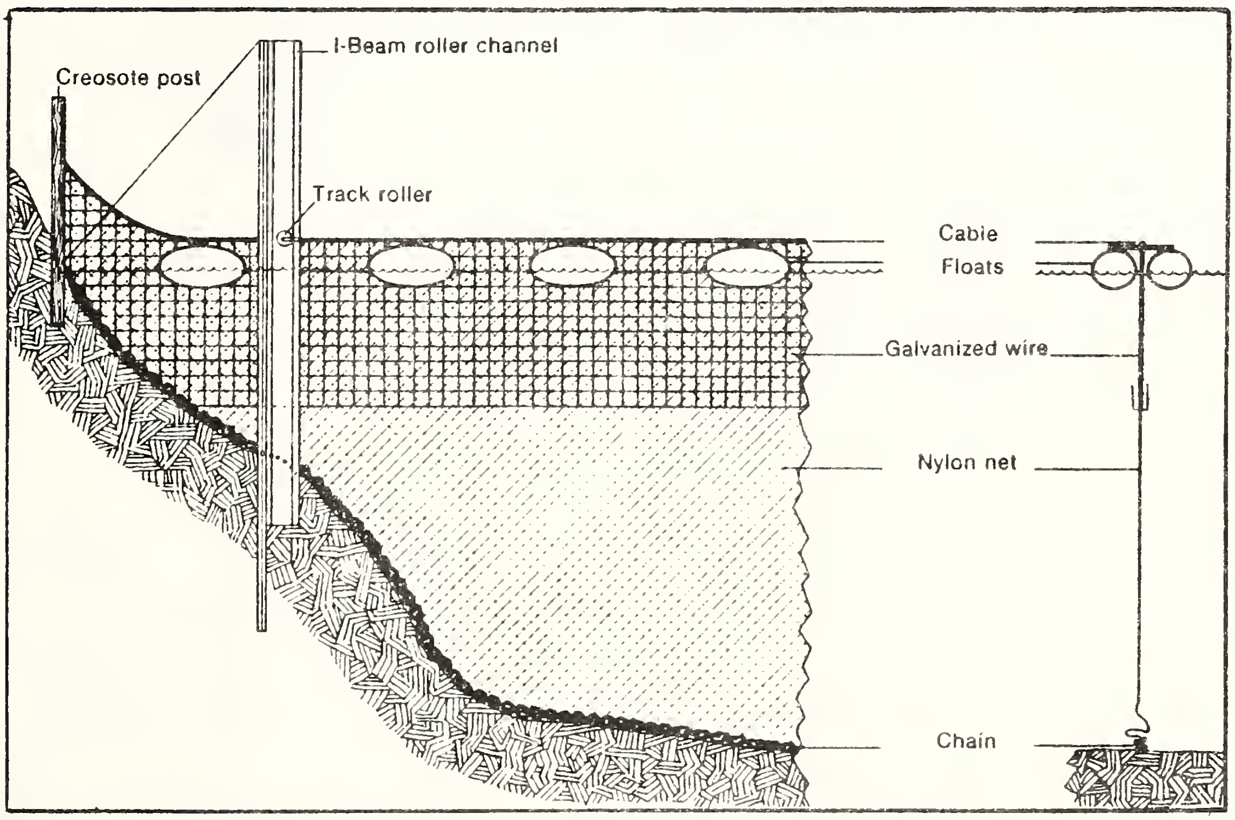


Figure 2-3. Nursery cove barrier.

Source: Nelson et al. 1978

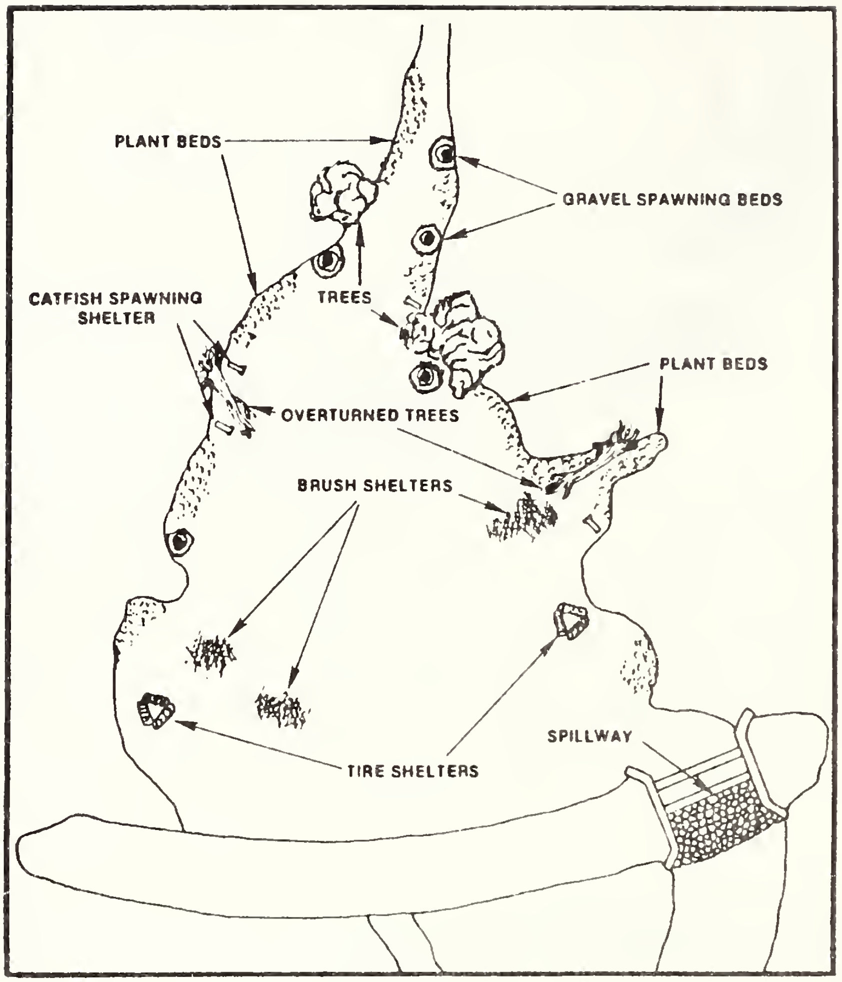


Figure 2-4. Placement of fish attractors.

Source: Ambrose et al. 1983

design sometimes is nothing more than anchored brush piles, Christmas trees, or cedar trees (Figure 2-6) (Wilbur 1974).

Brush attractors should be built from durable hardwoods or cedar and installed in areas 10 to 15 feet deep (but above the zone of summer and winter stagnation). Structures should be securely bound to prevent disintegration, spaced about 150 feet apart, and anchored on weed-free, hard-bottom sites.

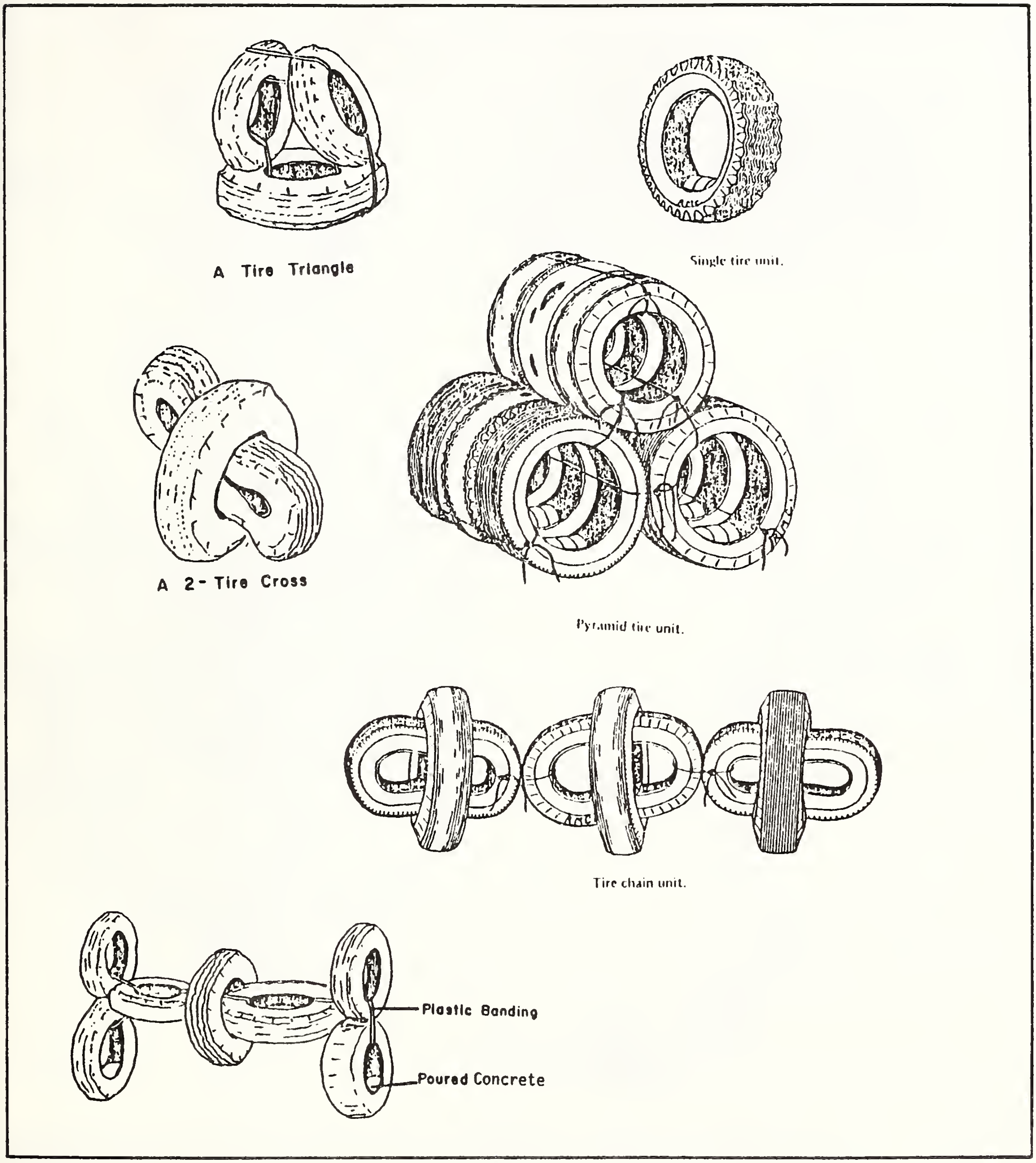


Figure 2-5. Tire attractors.

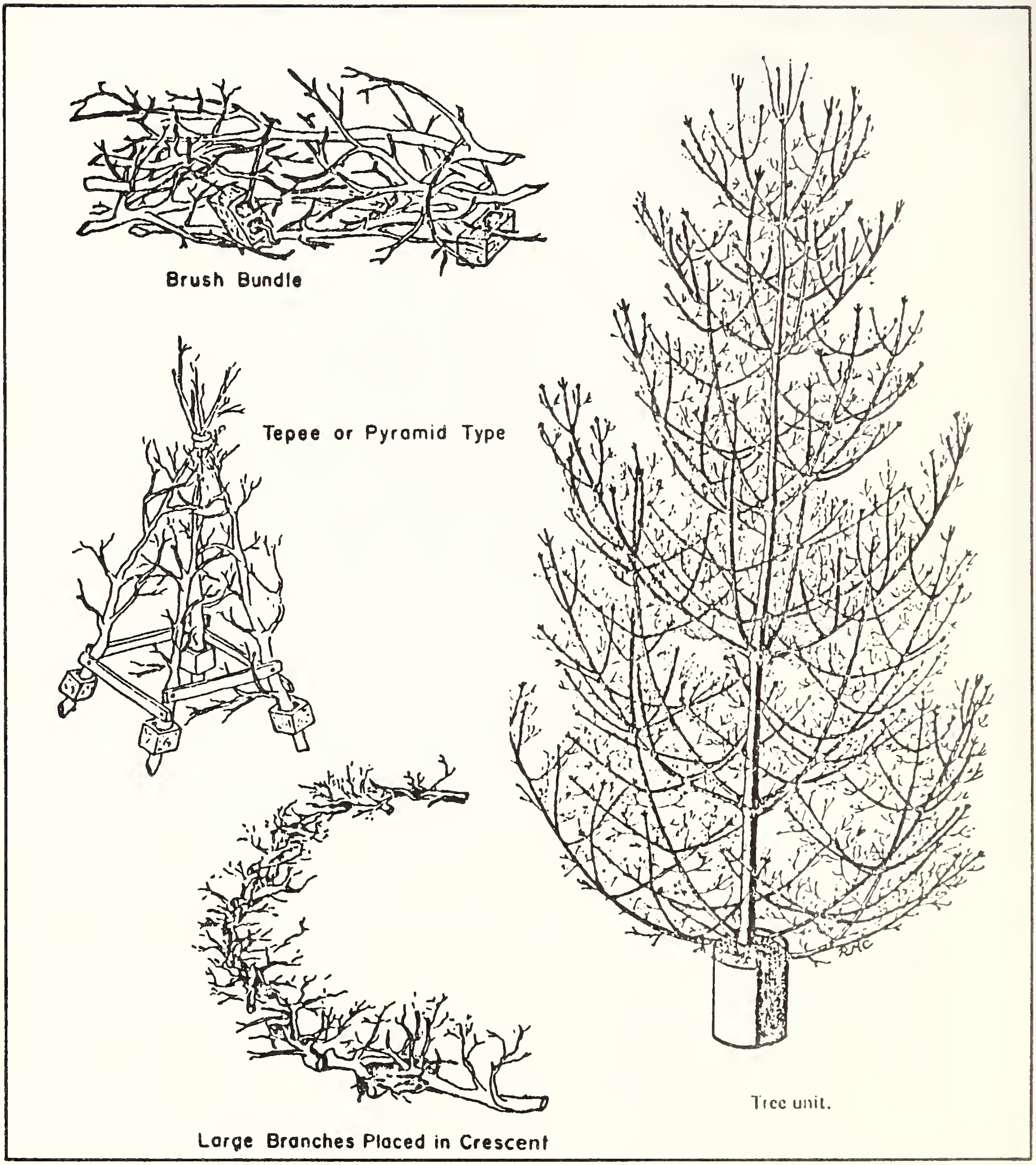


Figure 2-6. Brush attractors.

One of the easiest ways to create shoreline attractors is to fell trees into the water. In northern latitudes, drop the trees on the ice, trim if necessary, and weight with ballast, leaving the trees to sink into place as the ice melts. In reservoirs with water-level fluctuations, trees may be felled, positioned, and weighted with ballast during drawdown periods.

Plastic Attractors

Buoyant, black polyethylene plastic strips cut 2 inches wide and 8 to 12 feet long can create "kelp clumps." Clumps of 25 to 30 strips are held together by a base weight and are strung together to facilitate placement, maintenance, and recovery of the structures. Hiscox (1976) listed the following advantages of kelp clumps over more elaborate systems:

(1) The entire system is movable.

(2) As the water level recedes, the artificial cover collapses to a low profile that presents little hazard for boats, water skiers, and other users.

(3) The lack of tangible materials discourages vandalism.

Stake Beds

The Tennessee Game and Fish Commission uses stake beds to concentrate crappies (Petit 1972). A 4- by 8-foot bed is constructed by driving 15 stakes 4 to 7 feet long into the lake bottom (Stone 1978).

Clay Pipes

Pipes are bundled with plastic binding material to form a pyramid of irregular shape, with pipes of different diameters incorporated to create habitat diversity. Typically, several units are used in aggregate.

Midwater Attractors

Midwater fish attractors were originally designed to attract commercially harvestable quantities of coastal pelagic fishes (Klima and Wickham 1971, Reeves et al. 1977), but they also are useful for attracting freshwater species. Smith et al. (1981) found that artificial midwater structures attracted six game-fish species--spotted bass, bluegills, white crappies, white bass, redear sunfish, and largemouth bass. The attractors are composed of buoyant objects of variable design held suspended some distance below the water surface by an anchoring system. Structural shapes used are tents, inverted cones, and horizontal platforms (Figure 2-7).

Standing Timber

The need for artificial cover structures may be reduced or eliminated by retaining areas of brush or standing timber in new reservoir basins. While biologists usually favor leaving some standing timber for fish cover in lakes, engineers, hydrologists, and navigation authorities usually oppose this practice. Ordinarily, compromise procedures can be worked out. Where the standing timber is composed of coniferous species, forest pathologists and fire-control personnel advocate a 100-foot clearance strip along the shore.

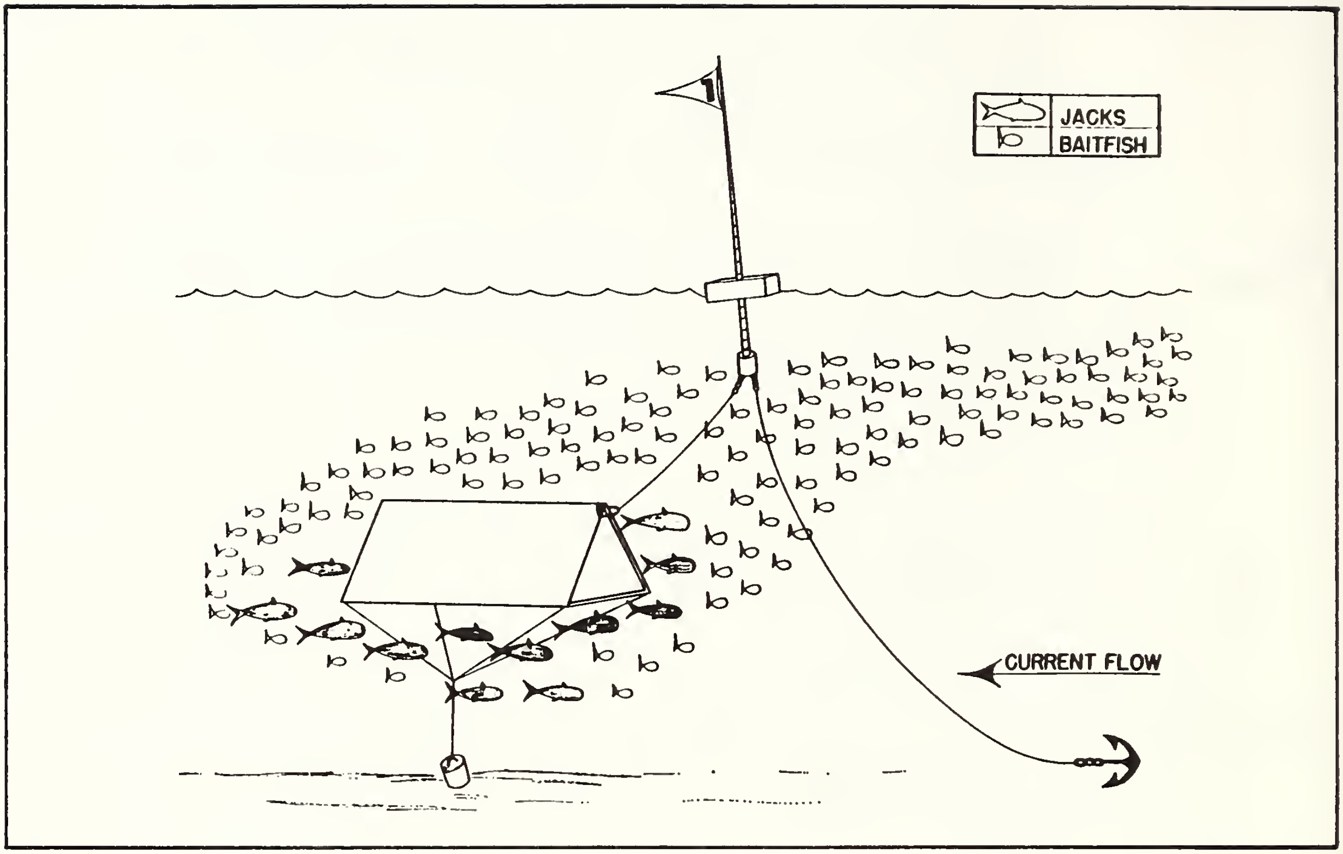


Figure 2-7. Midwater attractors.

Source: Klima and Wickham 1971

The most impressive demonstration of the effects of flooded standing timber was made on Bull Shoals Reservoir in Missouri. Of the 2,380-acre reservoir, 6.3 acres were left in emergent, inundated timber. During 1959, it was found that there were 5,138 hours of fishing per acre in timbered areas, as compared to 97 hours per acre in the rest of the census area. The hook-and-line harvest in the timbered areas was 3,054 pounds per acre and, in the rest of the area, about 113 pounds per acre (Jenkins 1970). Other studies have shown similar, if less dramatic, results.

Of course, this does not mean that flooded timber produces 3,000 pounds of fish per acre, whereas open water produces only about 100 pounds per acre. Nevertheless, fish are attracted to these areas by the presence of cover and food, and they are concentrated so that fishermen can better harvest them. As fish in the timbered areas are caught, other fish move from open water into these more favorable ecological niches where more food and cover are available. A less obvious factor in these statistics is the

many fishermen who come to these timbered areas to escape competitive water uses, such as boating, waterskiing, and swimming.

FISH POPULATION CONTROL IN LAKES

The primary objective of fish population control is to restore balance to fish populations. Typically, some environmental change is responsible for the imbalance, whether it is one of species, numbers, or size. Physical or chemical changes--changes such as dam structures, channel modifications, pollution, or changes in temperature, turbidity, or fertility--favor more adaptable and tolerant species. Unless these environmental factors are recognized and rectified, benefits arising from management programs become short-lived.

Several means can be used to determine the buildup of undesirable fish populations. If the "unwanted" fish are susceptible to the fishing gear and methods being used, creel censuses will show the increases. The same is true of netting or trapping surveys, or of electrofishing surveys, which also can be used to sample the composition of fish populations. Over time, an exacting study of the growth rates of competing species can be instructive.

Once a problem has been established, a number of corrective actions may be taken. In lake reclamation, the methods and objectives are basically the same as for streams, with various methods that can be used to control undesirable fish such as netting, trapping, electrofishing, water-level manipulation, drainage, changing fishing regulations, commercial fishing, stocking, and chemicals. As in the rehabilitation of stream fisheries, it should be ensured that the State is cooperatively involved in planning and implementing the project work. As a basis for this partnership, a review of these control procedures and partnership techniques is covered in this section.

Nets and Traps--Mechanical Removal

The use of nets and traps often has met with poor success, typically because an inadequate fraction of the population is removed when compared with the effort. Lennon (1971) estimated that 80 percent of a stunted population must be removed from a lake before any measureable change can be achieved. Depending on the type of gear used, small adverse impacts on nontarget species also may occur as with gill nets, which are size-selective and kill fish. However, in view of the success of some rough fish removal projects, damage to nontarget species often is insignificant compared with the benefits to sport fish populations. Some studies have even indicated that removing a portion of a population results in greater survival and growth of the remaining portion.

Electrofishing

Electrofishing, while successful as a fish population sampling method, is only of limited success as a control method. Electric shockers are generally ineffective in clearing waters of undesirable species (Bennett 1962).

Water-Level Manipulation

Drawdowns, which generally are used to control rough fish and overabundant forage species, can be used to control fish populations by exposing spawning areas and eggs, stranding small fish in weed beds and shallow pools, and concentrating other fish in open water areas, thereby increasing their availability to anglers, commercial harvest, and predation (Dunst et al. 1974). Refer to Bennett et al. (1969), Snow (1971), Dunst et al. (1974), and Beard (1971) for proper timing and degree of drawdown. Success of this technique depends on controlling water levels skillfully and with a definite understanding of biological aims (Buchanan et al. 1974, Headrick et al. 1975). Conversely, unregulated fluctuations are detrimental to the fish community.

Drainage

Small artificial lakes can be drained to control the composition of the fish population. Cool periods of the year are best for draining operations because of minimum loss from fish handling. Beneficial effects of drawdowns and drainage include compaction and aeration of sediments (Nichols 1974) and desirable changes in plant communities.

Commercial Fishing

Commercial harvest of rough fish is beneficial--or at least not harmful--to sport fishing in some waters (Bennett 1962). To make such a commercial operation profitable, it is essential that the target species exist at high population levels. However, intensive fishing often depletes the commercial fishery, making it unprofitable in the long run. Typically, waters would be managed for sport fishing by the State (Calhoun 1966).

Fishing Regulations

Harvest regulations for anglers also can be used to regulate populations by removing or relaxing regulations that restrict the catch of overabundant species. Underfishing and overfishing can have negative effects on the populations; however, if the angler harvest is properly regulated, no adverse effect on the fishery should ensue from angling. To stimulate the harvest of underutilized fish, a number of States have even published leaflets or pamphlets giving recipes for preparing such fish. (See Regulating Dams in Chapter 1.)

Removal by Spearfishing

A number of States permit rough fish to be caught by various impaling devices, such as fish spears, pitchforks, or bows-and-arrows. While these implements have proved to be much more efficient fish catchers than hook-and-line fishing methods, some groups of fishermen oppose their use, claiming that those using these methods also catch or injure game fish.

Stocking

Stocking fish can, in certain situations, adversely affect native fish populations. Dilution of high-quality, wild-stock gene pools, as well as immediate stress from crowding, has been observed in some waters (Schnick 1972). The total impact of stocking exotics is seldom clear until several years after their introduction--as was the case with carp. On the other hand, stocking predatory species can be part of an integrated renovation program, with stocked

fish reducing fishing pressure on native stocks and providing diversity for anglers. (See Regulating Dams in Chapter 1.) Stocking has had significant benefits where lakes were formerly barren, such as the salmon rearing program in Alaska.

Chemical Toxicants

Although general fish toxicants, such as antimycin or rotenone, usually are applied to kill all fish in a body of water, they can be used for selective kills of fish under special circumstances. (See Regulating Dams in Chapter 1.)

The objective of total reclamation is to kill all fish present in the target area, and it is the more common of the reclamation processes. A partial reclamation usually refers to the poisoning of only that part of a body of water that contains the target species, such as the treatment of the epilimnion of a thermally stratified lake to kill warm-water species. Spot treatment, a variation of partial reclamation, is practiced with a suitable toxicant against localized concentrations of target fish, such as congregations of spawning carp in a marsh.

Controlling fish in lakes differs from stream reclamation in the following respects:

(1) Application Methods. Small lakes should be drained so that the residual population in the channels and potholes can be controlled, using stream reclamation techniques. In the case of ponds and lakes that cannot be completely drained, motorboats, gasoline-powered pumps, backpack pumps, and even porous bags can be used to apply toxicants. In homothermous lakes, spraying the surface waters is usually sufficient, but in thermally stratified lakes, both surface and deep pumping through weighted hoses is necessary. Some companies even put out specially formulated sand to facilitate dispersal in this type of lake.

(2) Detoxification. Detoxification can be handled in several ways. In ponds that have been drained, outlets should be closed as the toxicant is applied. By the time the pond is completely filled again, the concentration will ordinarily be diluted below lethal levels. Another way to detoxify a lake is to set up a detoxification station at the overflow point, while another is to distribute the detoxifying agent in the ways used for toxicants (boats, pumps, and so forth).

(3) Selective Kills. In some warm-water pond reclamation projects, the objective is a partial or selective kill. Partial kills should be used in ponds with overpopulations of fish, with kills being used on fish populations such as gizzard shad that are especially susceptible to toxicants such as rotenone.

Rotenone

Since the mid-1930's, the toxicant rotenone has been the principal agent used for controlling undesirable fish populations. It has several advantages that make it valuable for fish population control, the most important of which is its low toxicity to mammals, birds, and reptiles. In addition, fish killed by rotenone can be safely eaten by humans, and the chemical is not overly dangerous to the applicator. Shad, often problem fish, are so sensitive to rotenone that they can be selectively killed without harming game fish. However, attempts to selectively eradicate other target species have been less successful. Waters in which rotenone has been applied can be detoxified by applying potassium permanganate at a rate of approximately 1 part per million (ppm).

On the other hand, rotenone has certain disadvantages: it is relatively costly; it often shows poor vertical dispersal through stratified-density layers in lakes; fish avoid it; it is ineffective in colder waters (which can be offset somewhat by increasing the dosage and awaiting a slower reaction); and some target species (such as the bullheads) are quite resistant to the chemical.

The combination of these drawbacks makes it difficult to obtain complete control with rotenone. Except in small, shallow waters, a total kill usually cannot be obtained. Moreover, inlet or outlet flows, areas of heavy plant growth, deep water, bottom spring flows, and lake stratification present problems that require special efforts to obtain desired results.

Although a few large lakes have been treated with rotenone, such projects generally are not feasible because of the high costs and low chance for obtaining lasting benefits. Total control can rarely, if ever, be attained on large, on-channel lakes or reservoirs. Another drawback is that, even when good control is achieved, the high spawning potential of rough fish species rapidly nullifies the benefits.

To reestablish a proper population balance, rotenone is sometimes used to treat shoreline areas or a section of a small warm-water lake to reduce numbers of certain species. In the attempt to restore conditions favorable to game fish, an arm or bay of a large lake may be treated if it is known that an undesirable species is concentrated there by habitat preferences during a particular time period. Although light doses of rotenone have been used to selectively reduce numbers of gizzard shad in large reservoirs, other chemicals may prove more advantageous in controlling undesirable species in large lakes and reservoirs.

What applies to the use of rotenone in streams (see Regulating Dams in Chapter 1) also applies to lakes and reservoirs. The application of 2.7 pounds of 5 percent rotenone per acre-foot will provide a concentration of 1.0 ppm, while 1 gallon of the emulsified form will treat 3 acre-feet under normal conditions. The powdered rotenone is mixed with water to form a slurry that can be sprayed by power pump and hose, or applied by a boat bailer device (a Venturi pump) attached to the outboard motor. The same methods apply to the emulsified form. Recently, aerial application, mainly by helicopter, also has been used successfully and shows much promise.

Antimycin A

An antibiotic isolated from a fungus-like bacterium, antimycin A (trade name: Fintrol) shows much promise as a fish toxicant. Its chief advantages appear to be its effectiveness in very low dosages, rapid dissipation, low mammalian toxicity, effectiveness in the presence of aquatic plants and temperature-stratified water, and its specificity at different dosages. Carp are vulnerable to low concentrations, and yellow perch have been completely controlled at 0.5 ppb (parts per billion) with no mortality noted in desirable species. Gar, bowfin, and catfish are more resistant. The time required for complete dissipation varies between 2 days and 2 weeks. It is nontoxic to mammals at 1.0 ppb (Table 2-1).

The antimycin is impregnated in sand and is designed to release the chemical at various depths (for instance, at 0 to 5 feet and 10 to 15 feet). The chemical can be applied by hand or with a mechanical broadcasting device. If it is necessary to detoxify the water after applying the antimycin, potassium permanganate can be added to oxidize the antimycin, as with rotenone. Potassium permanganate, at the rate of 1.0 ppm, is effective in deactivating 10 ppb antimycin when immediate detoxification is necessary.

Other Chemicals

Certain other chemicals, especially insecticides, are used as fish toxicants, but they are not recommended for general use because of residual toxicity and potential harm to other fauna. All chemical toxicants should be considered as generally hazardous and as environmental contaminants. Their use should be made as specific as possible to target organisms, and detailed preliminary and followup studies should be carried out. A checklist of preliminary observations for reclamation of standing and flowing waters is presented by Lennon and Berger (1970) and Lennon et al. (1970).

Table 2-1. Tolerance limits of fish species for antimycin A.

Fish Species	Time (hours)	Temperature (°C)	Concentration (parts per billion)
Rainbow and brown trout	24	12	0.4-0.6
Gizzard shad	24	12	0.8
	24	22	0.04
Perches	24	12	0.66
	24	22	0.08
Pike	24	12	0.8
	24	22	0.1
White sucker	96	12	0.22
Bigmouth buffalo	96	12	0.4
Sunfish	24	12	1-6
	24	22	0.2-0.8
Carp	24	12	2
	24	17	1
Goldfish	24	12	100
	96	22	0.6
Stone rollers	24	12	1
Channel catfish	24	12	1
Black bullhead	24	12	100-120
	24	22	40

AQUATIC PLANT CONTROL

Aquatic plants are necessary components of aquatic ecosystems, providing food and habitat for fish and wildlife, protecting shorelines from wind and wave erosion, and providing quality fishing locations for anglers. Moreover, the blossoms of some aquatic plants, such as American lotus, are valued for their aesthetic contribution.

On the basis of these and other considerations, the elimination of all plants in an aquatic ecosystem is never desirable (Dillard 1975). However, excessive dense growth of aquatic vegetation can interfere with recreational and aesthetic uses of waterways. Such

growth creates potential health hazards to humans and animals (Applied Biochemists, Inc. 1976). From a fishery perspective, overly abundant aquatic plants can lower the concentration of dissolved oxygen, making angling difficult, and they can upset the balance of the fish community by providing too much cover for small fish (Klingbiel et al. 1968).

Aquatic Vegetation Groups

Aquatic plants are classified as algae, submergent plants, emergent plants, and floating plants. Their susceptibility to control measures varies according to physical and biological characteristics of the group and individual species.

Algae

There are three general classes of algal growth: phytoplankton, filamentous algae, and branched algae. (The latter two categories are sometimes combined.) Phytoplankton, tiny one-celled plants, some microscopic in size, are free-floating plants that form the so-called "bloom" of lakes and ponds when their populations build up to high densities. Some of the blue-green algae cause taste and odor problems in water, and several genera of this group (Microcystis, Anabaena, Aphanizomenon) produce toxins capable of killing fish, birds, and mammals.

Filamentous algae consist of growths of long, stringy, hair-like strands often with a slick or slimy coating. One (Hydrodictyon) forms a hair-net-like growth. Filamentous algae are attached to the bottom or to submerged objects, but they do not have true roots. When they die or are broken loose, they entrap gas bubbles and accumulate on the surface, forming a floating surface mat that is often referred to as "pond scum."

Branched forms attach to the pond or lake bottom and, since they appear to have stems and leaves, are often mistaken for higher plants (milfoil and coontail). Some (Chara, Nitella) are bristly, because of encrustment by precipitated carbonates, hence Chara's common name of "stonewort." Such branched algae are usually more difficult to kill than others, and they require higher chemical doses.

Submerged Plants

Submerged plants have true roots, stems, and leaves. Ordinarily, the entire plant, except perhaps a few floating leaves or flowers, grows beneath the water surface. There are hundreds of species, and they vary widely in susceptibility to chemical control. Common members of the submerged community include the pondweeds, coontail, watermilfoils, waterweed, and waterbuttercups. Because of their dependence on photosynthesis for life processes, these plants are restricted to water depths that solar radiation can penetrate and thus are usually absent from the deeper portions of lakes.

Emergent Plants

Emergent plants stand in water with the stem supporting part of the plant above the water surface. They include the marginal or shoreline plants of the shallow waters. Most are waxy-leafed plants and are little affected by water turbidity, since most of their chlorophyll-bearing parts extend above the water. Typical of this group are cattails, bulrushes, wildrice, burreeds, sedges, and pickerelweed.

Floating-Leafed Plants

This group includes free-floating plants and those attached to the bottom but with leaves supported at the surface. Plants in this category are waxy-leafed and include duckweed, waterlily, watershield, cowlily, and American lotus.

Identifying Aquatic Plants

Since aquatic plants often differ in their susceptibility to control chemicals, it is first necessary to identify the problem plant to at least its genus, and sometimes to its species. A complete treatment of the systematics of aquatic plants is too voluminous to include here, and reference to botanical keys is advised.

There are several good guides to aquatic plants. Some of these include all the macrophytes (excluding the algae), and others consider only the algae. Some of the better references on the subject are Fassett 1966, Muenscher 1944, and Smith 1950.

Aquatic Weed Control Methods

There are four categories of control methods: mechanical, habitat manipulation, biological, and chemical.

Mechanical Control

Mechanical control of nuisance aquatic plants has been practiced for centuries (Robson 1974). The technique involves collection of plants, followed by subsequent treatment and return to the water or by removal from the infested body of water (harvest method). Usually plants are harvested by hand or machine and transported to shore, where they are either deposited or transported elsewhere for disposal or use. A significant advantage of mechanical harvest control is the potential use of plants as animal feed and soil conditioners (Nichols 1974).

In small ponds, emergent plants can be controlled by merely pulling up or breaking off the pestilent plant by hand or by use of a hand sickle or scythe. This is not practical on large waters or for plants other than those of the emergent group. A somewhat more efficient technique is to drag a length of barbed wire or chain through the body of water. This usually is done by two people. Weeds are broken off or uprooted. It is a laborious method and is limited in application to small ponds, marshes, or potholes.

Motorized equipment consisting of boat-mounted mowing bars has been developed for mechanical control of water weeds. Much larger areas can be cleared of weeds with these mowers, and they can be adjusted to cut at a level of 4 or 8 feet below the surface. However, the period of regrowth is relatively short, and repeated mowing is needed during the year.

Types of machinery used for harvesting aquatic weeds are described by Livermore and Wunderlich (1969). Nichols (1974) lists manufacturers of weed-harvesting equipment. The choice of equipment--whether harvesters, transporters, or weed ploughs--depends on several factors: the type of plant to be harvested, the type of water body, debris or other foreign matter encountered, the characteristics of the shoreline, prevailing weather conditions, the harvesting concept used, and the plant disposal method contemplated. Other important factors related to the objectives of management plans are cost, results, and ecological implications (Walsh 1981). Mechanical aquatic plant harvesting and harvester systems are evaluated by Culpepper and Decell (1978), Koegel et al. (1978), Koegel et al. (1974), and Livermore et al. (1975).

Habitat Manipulation

The objective of habitat manipulation is to limit plant growth by altering one or more of the physical or chemical factors critical to growth, such as light, bottom types, and wind (which affect the location of plants) or by altering factors that influence the physiological processes of plants (Nichols 1974). Because it is possible to control plant growth through the limitation of any one of these factors, many techniques have been developed, such as shading, dredging, overwinter drawdowns, flooding, nutrient limitation, and blanketing with sand and gravel.

Shading. Shading can be done by using light-occlusive dyes or installing opaque black polyethylene sheeting. Both techniques reduce or eliminate the light needed for active photosynthesis. The use of these techniques generally is restricted to small water areas. Dyes can be used to treat the whole pond, while the opaque plastic sheeting can be used to treat individual, separate areas (Dawson and Kern-Hansen 1979, Mayhew and Runkel 1962). Plastic sheeting can be suspended on floats or spread over the bottom of boat channels, boat launching sites, dock areas, and so forth. However, the use of plastic sheets needs to be further evaluated as to their durability and long-term cost.

Inorganic Turbidity. Keeping a lake or pond constantly muddied will tend to limit the amount of submerged plant growth by lowering the light penetration in water. This is a contributing factor to the phenomenon of lower densities of aquatic plant growth in areas where large populations of carp roil the waters during their feeding activities. However, this method of submerged plant control is not practical to apply and has ecological consequences for all life in the water body.

Organic Turbidity. Controlling submerged weeds by fertilizing waters is widely used in the Southeastern United States. The addition of nutrients to water (in the form of commercial fertilizers) commonly causes an increase in phytoplankton, which shade the submerged plants so they cannot photosynthesize. In the Northern States, however, fertilizers often produce undesirable filamentous algae instead of plankton algae. Several application methods are possible. One method is to pour the fertilizer as a thin stream into the water behind a boat. Another method is to place it on a platform 6 to 12 inches below the water surface. Another method some States prefer is to use floating dispensers that slowly release the nutrients into the water. Several applications should be made at 10-day intervals until a white object cannot be seen at a depth of 12 to 14 inches below the water surface. Fertilizer should be added periodically, as necessary, to maintain that dark green turbid color whose shading effect will prevent the development of submerged plants (Soil Conservation Service 1983).

Dredging. Dredging is used to lower the lake bottom below the limit of light penetration, thereby eliminating the light needed for plant growth. While shallow-water dredging has little utility for plant control, deep dredging can be an effective long-term aquatic plant control technique (Nichols 1974). Peterson (1981) provides a comprehensive review of dredging techniques. The principal drawback to dredging is its cost.

Bottom Blanketing. Bottom blanketing is done with a 6- to 8-inch layer of sand or gravel that is often put over sheets of perforated black plastic that reduces nutrient transport from covered sediments and may prevent mixing of the blanket material with the covered sediments (Nichols 1974). Blanketing with sand and gravel is difficult, costly, and may limit the production of benthic invertebrates (Born et al. 1973). However, gravel blanketing can provide desirable spawning substrate for some fish, and sand blanketing can create quality swimming areas.

Drawdown and Flooding. Overwinter drawdowns expose plants to freezing and desiccation. It is an effective method of control for certain species but may promote the growth of others (Table 2-2). Nichols (1972) has applied winter drawdowns successfully. (See Nichols (1974) for references on the influence of drawdowns on aquatic plant species.) Flooding also has been used to control the common cattail (McDonald 1955) and also may control submergent aquatic plants (Robel 1962), though its utility for this purpose is limited.

Nutrient Limitation. Nutrient limitation is another useful technique, particularly for algae control. Two methods are used: dilution and inactivation of nutrients (Nichols 1974). The first method, dilution, simply involves diluting a nutrient-rich lake

Table 2-2. Drawdown and flooding.

Species[a]	Source: Nichols (1972)	Nichols (1974)	Beard (1973)	Lantz et al. (1964)
American bulrush			U	
American wildcelery	U		U	
Bladderwort	C			C
Bur-marigold			I	
Canadian waterweed			U	
Common arrowhead			U	
Common bladderwort			U	
Common cattail	I		U	
Common ducksmeat			U	
Common hornwort	U	C	C	
Common pickerelweed	C			
Cowlily	C	C	C	
Duckweed			U	
Flatstem pondweed			U	
Floating leaf pondweed			U	
Floating knotweed	I			
Grassleaf pondweed	I			
Greenfruit burreed			U	
Hemlock waterparsnip	I			
Largeleaf pondweed	C		C	
Leafy pondweed	I			
Marsh cinquefoil	C			
Marsh knotweed	I		U,I	
Needle spikerush	C		U	
Northern mannagrass	I			
Ribbonleaf pondweed	I		U	
Rice cutgrass	I			
Richardson pondweed	I		U	
Robbins pondweed		C	C	
Sandbar willow	I			
Schreber watershield	C		U	C
Slender naiad	I		I	
Softstem bulrush	I			
Stiff wapato	C			
Swamp milkweed	C			
Sweetflag	I		U	
Waterlily	C			C
Watermilfoil			C	
Waterthread pondweed			I	
White buttercup			U	

[a]Common names largely follow Scott and Wasser (1980).
C = controlled; U = unaffected; I = increased.

with increased water flows from a nutrient-poor source (Born et al. 1973). In the case of the second method, nutrients can be inactivated by precipitating them with alum, fly ash, or clay. Peterson et al. (1973) describe nutrient inactivation procedures used successfully on Horseshoe Lake, Wisconsin. Peterson et al. (1973) list the following benefits of nutrient precipitation with alum:

(1) Total phosphorus in the lake decreased during the summer after treatment.

(2) No large increase in total phosphorus occurred in the hypolimnion during the following two summers.

(3) Some increase in the transparency of the water was apparent during the summer after treatment.

(4) Water color decreased for a short time.

(5) Nuisance planktonic algal blooms common during previous years did not appear.

(6) Dissolved oxygen conditions improved markedly, particularly during the following few winters.

(7) No adverse ecological consequences were observed.

Biological Control

Biological control measures have great potential for effective, economical, and permanent control of nuisance aquatic plants (Walsh 1981, Schuytema 1977). Biological controls are not intended to eliminate nuisance plant species but rather to reduce them to a nonnuisance density. Control is successful if the predator (control) and nuisance plant reach a state of equilibrium and if balance is restored to a level that existed before the nuisance appeared (Schuytema 1977). Exotic weeds are considered good candidates for biological control, the idea being that they are out of control because their natural enemies have not accompanied them to this country and that they will be susceptible to the introduction of organisms to prey on them or infest them. Certain native weeds also may be controlled by similar methods (Bennett 1974).

Biological control organisms proposed or used as aquatic plant control agents fall into three categories:

(1) Plant pathogens. Pathogens include viruses, bacteria, and fungi.

(2) Invertebrates. Invertebrates include insects, mites, snails, and crayfish.

(3) Herbivorous fish. Fish that show potential as biological control agents are the grass carp and tilapias. Turtles, waterfowl, and mammals also have been investigated as potential biological control agents, but their utility was judged to be limited by Schuytema (1977), who published a comprehensive review of aquatic plant control organisms.

Chemical Control

While controlling aquatic plants with herbicides may be the simplest and least expensive control method (Walsh 1981, Applied Biochemists, Inc. 1976, Blackburn 1974), herbicides can have undesirable effects such as lack of specificity, toxicity to nontarget organisms, and occasionally persistent residues. Plant growth regulators and herbicides are relatively nonpersistent in the environment compared to all pesticides, but they cause significant changes in aquatic ecosystems. Their impacts must be judged in relation to (1) the toxicity to the target species, (2) the relative toxicity to nontarget species, (3) the fate of residues and their significance to water, fish, crops, livestock, and food, (4) the environmental factors that affect toxicity, efficacy, and persistence, and (5) the synergizing or antagonistic activity of carriers, formulations, metabolites, degradation products, or other pesticides (Gangstad 1978).

Herbicides. A number of herbicides have been used to control aquatic plant populations, but only seven are now registered for use in food-fish environments: chelated copper, copper sulfate, 2,4-D, Diquat, Endothall, Glyphosate, and Simazine. Table 2-3 lists the effective herbicides for particular aquatic vegetation. DeVaney (1967) published a much more extensive list of plants that can be effectively controlled by herbicides.

Following are the seven herbicides approved for aquatic use in fish environments. Specific information on herbicides provided was extracted by Schnick et al. (1982) from the Weed Science Society of America (1979), the Fish and Wildlife Service (1979), EPA Compendium of Registered Pesticides, Volume 1 (U.S. Environmental Protection Agency 1974), and Applied Biochemists, Inc. (1976).

(1) Copper chelate (Copper II alkanolamine complex)
Commercial product names: Cutrine-Plus, Algaetrol-76, Mariner A, Stockrine Algaecide, and others.
General information: Copper chelate is registered for use as an aquatic algicide. Copper chelates appear to be photosynthetic inhibitors that weaken cell membranes. These compounds are generally nontoxic to fish and wildlife unless applied in very soft water (fewer than 20 ppm $CaCO_3$).

Table 2-3. Herbicides effective for aquatic plant species.

Aquatic Plant	Effective Herbicides
Algae	
Planktonic algae (various species)	Copper sulfate, copper chelate, simazine, diquat, endothall
Filamentous algae (benthic, various species)	Copper sulfate, copper chelate, simazine, diquat, endothall
Muskgrass and nitella	Copper sulfate, copper chelate, simazine, endothall
Emergent plants	
Arrowhead	2,4-D
Bulrush	2,4-D, amitrolem diuron, glyphosate
Burreed	Dalapon, 2,4-D
Chafflower	2,4-D
Cattail	Amitrole, dalapon, diquat, glyphosate
Hibiscus or rosemallow	2,4-D
Justicia	2,4-D
Marshpurslane	2,4-D
Pickerelweed	2,4-D
Rush	2,4-D, glyphosate
Sedge	Amitrole, dalapon, 2,4-D glyphosate
Smartweed	2,4-D
Spikerush	Diquat

Table 2-3 (continued). Herbicides effective for aquatic plant species.

Aquatic Plant	Effective Herbicides
Emergent plants	
Waterhyacinth	Amitrole, 2,4-D, glyphosate, diquat
Waterleaf	2,4-D
Waterplantain	2,4-D, glyphosate
Submerged plants	
Bladderwort	Diquat, 2,4-D
Buttercup	Diquat
Common hornwort	Diquat, endothall, simazine, 2,4-D
Fanwort	Endothall, simazine, 2,4-D
Hydrilla	Diquat
Naiad	Diquat, endothall, simazine, 2,4-D
Pondweed	Diquat, endothall, simazine, 2,4-D
Waterchestnut	2,4-D
Watermilfoil	Diquat, endothall, simazine, 2,4-D
Waterweed	Diquat, endothall, 2,4-D
Floating-leaved and free-floating plants	
Burreed	Endothall, 2,4-D
Cowlily	Endothall, 2,4-D, glyphosate

Table 2-3 (continued). Herbicides effective for aquatic plant species.

Aquatic Plant	Effective Herbicides
Floating-leaved and free-floating plants	
Duckweed	Diquat, simazine, 2,4-D
Lotus	Endothall
Pennywort	Diquat, 2,4-D
Salvinia	Diquat
Waterhyacinth	Diquat, 2,4-D
Waterlettuce	Diquat
Waterlily	2,4-D, glyphosate
Watershield	2,4-D
Waterstar mudplantain	Diquat, endothall, 2,4-D

Source: Schnick et al. 1982

Vegetation controlled: A broad range of algal species. A granular formulation is especially effective against muskgrass and nitella.

(2) Copper sulfate (Cuprice sulfate pentahydrate)
Commercial product names: Agway Copper Sulfate, Algimycin PLL-C Slow Release, Diamond Copper Sulfate Bluestone, Mariner M, and others.
General information: Copper sulfate has the same mode of action as copper chelates. However, it is a far more corrosive compound and readily precipitates as copper carbonate in hard water.
Vegetation controlled: Planktonic and benthic algae.

(3) 2,4-D (2,4-diclorophenoxyl acetic acid)
Commercial product names: Aqua-Kleen, Rhodia, 2,4-D, Riverdale 2,4,-D Granules, Transvall Weed-Rhap, Vegatrol A-4D, Visko-Rhap 2D, Weedtrine II.
General information: This herbicide is nontoxic to mammals but gives a phenolic taste to water that may last for many months. It is used on agricultural land, rangeland, forest

land, and on aquatic sites. The chemical acts as a plant hormone that stimulates growth and kills plants by having them outgrow their food supply. It gives fish an unpleasant flavor, and the label of 2,4-D restricts the use of water in treated areas, with swimming restricted for 1 day and other uses, such as public drinking water, stock watering, and irrigation, restricted for 3 days. (These restrictions apply only to the treated area and to a relatively small marginal or buffer zone around the treated areas.)

While the chemical is not harmful to people, livestock, or wildlife, drift can damage crops for miles downwind. (Amine formulations of 2,4-D have less drift from volatilization.) For best results, foliage must be thoroughly wetted, and repeat applications may be required. Also, because it is very difficult to wash 2,4-D out of spraying equipment, a separate sprayer should be used only for 2,4-D to ensure against accidental damage to crops or ornamental plant losses. Vegetation controlled: Emergents and submergents, as well as floating plants, broadleaf weeds, and brush.

(4) Diquat (9,10-dihydro-8a, 10a-diazoniaphenanthrene-2A)
Commercial product names: Diquat Water Weed Killer, Diquat 2 Spray, Ortho Diquat, Reglone, Weedtrine-D, Aqua-Quat.
General information: Diquat is a contact herbicide that is used as a noncrop weed killer, a general aquatic herbicide, and "top killer" for agricultural use. An important and unique property of diquat is its rapid and complete inactivation by soil. A quick-killing herbicide that is absorbed by plant tissue, Diquat is most efficient on plants lacking an extensive root system. Water treated with the herbicide should not be used for human or animal consumption, spraying, or for overhead irrigation within 14 days after treatment, or until chemical analysis shows that the water does not contain more than 0.01 ppm of diquat (EPA 1982). Also, diquat should not be applied to muddy water.
Vegetation controlled: General weeds, filamentous algae, and submerged and floating aquatic vegetation.
Specific comments: Experiments by Barrett (1981) indicated that diquat can achieve localized control of aquatic vegetation in fast-flowing water when it is used with a carrier, like sodium alginate, that forms a viscous solution that sticks to the treated plants.

(5) Endothall (3,6-endoxohexahydrophthalic acid)
Commercial product names: Aquathol formulations, Hydrothol formulations.
General information: Endothall, which is formulated as a dipotassium salt and as a di(N,N-dimethylalkylamine) salt of endothall, is a contact herbicide that interferes with vital enzyme activity. Treated water should not be used for irrigation or domestic purposes for 7 days after application.

Vegetation controlled: Pondweeds, burreed, hornwort, watermilfoil, naiad, and mudplantain.

(6) Glyphosate (N-(phosphonomethyl)glycine)
Commercial product name: Roundup.
General information: This herbicide, which is used for relatively nonselective weed control, is relatively nonpersistent in soil. Its effectiveness may be reduced by rainfall within 6 hours after application and negated by heavy rainfall within hours after application. Also, glyphosate is not for use with aerial spray equipment. Aquatic area uses include banks of small water impoundments, irrigation ditchbanks, or drainage ditchbanks. Glyphosate also has a temporary registration for use in food-fish areas.
Vegetation controlled: Broadleaf weeds, grasses, and floating aquatic plants.

(7) Simazine (2-chloro-4,6-bis(ethylamino)-s-triazine)
Commercial product names: Princep 80W, Princep 4L, Princep 4G; Aquazine 80W Algicide, Algimycin GLB-X, Gesatop, Primatol.
General information: Simazine, a temporary soil sterilant that acts through the roots and foliage of plants, can be used for control of aquatic weeds. While toxicity to mammals is low, water treated with the chemical must not be used for irrigation, livestock watering, or human consumption for at least 12 months after treatment. The chemical's use near crops or valuable plants should be carefully controlled. Meyer (1966) noted that simazine seems to be less effective for aquatic plant control than other available chemicals.
Vegetation controlled: Planktonic algae, filamentous algae, and submergents.
Specific Comments: Linde (1969), who reported on the use of simazine for grass and sedge control, stated that the treatment was effective and that residual effects (2 years later) prevented the growth of planted barnyard grass.

Cautions on Chemical Use. Before introducing any chemicals into water, certain precautions should be understood. Some States require a permit to use certain aquatic control chemicals, and some even require individuals using the chemicals to be licensed (or to have demonstrated their knowledge of these weedkillers and application techniques). While aquatic plant-control chemicals are generally less dangerous to handle than the synthetic insecticides, some are injurious to human health. The arsenicals are deadly poisons in concentrated solutions.

Polyneuritis can result from prolonged skin contact with 2,4-D and related compounds. These chemicals also can destroy terrestrial food crop plants: great care should be taken to avoid aerial drift of the sprays.

Unless users have extensive knowledge of and experience with using these chemicals, they should consult an aquatic biologist or a reliable professional applicator. In any case, plans for controlling aquatic vegetation in water supporting fish must be thoroughly coordinated with the State fish and game agency. Specific precautions to be observed for the safety of fish, wildlife, and humans are discussed and listed by Rollins and Warden (1964) and Applied Biochemists, Inc. (1976). Chemical methods of aquatic plant control may have the following undesirable effects (Walsh 1981, Dillard 1975):

(1) The chemical may lack target-plant specificity.

(2) The chemical may be toxic to nontarget organisms.

(3) Chemical residues may persist and limit water uses until the compounds degrade.

(4) Chemical treatments leave the dead plants in the water. Dissolved oxygen in water can be dangerously reduced when excess nutrients are released by decaying plant matter.

(5) The chemical may be potentially hazardous to the applicator.

FERTILIZING LAKES

Fertilizing lakes and ponds to increase fish production has been common for centuries in Europe and Asia (Mortimer and Hickling 1954). Fertilizing fishing water is done to achieve the following results:

(1) Increase Biologic Activity in the Food Chain and Produce More Game Fish Poundage. The closer the feeding habits of game fish to the base of the food chain, the greater the effect fertilizer will have on their weight (Everhart and Youngs 1981).

(2) Control or Eliminate Submersed Aquatic Weeds. Here, two objectives--controlling weeds and boosting fish production--often are accomplished simultaneously, making fertilization projects in many cases doubly beneficial. Results are better in some sections of the country than in others. In the Southeastern United States, where soils are often infertile, fertilization has given excellent results. Conversely, in the Northern States, fertilization projects usually create more problems than benefits (Bennett 1962). The first step before artificial fertilization is to conduct chemical tests of the water to determine if fertilization will improve some basic deficiency; if not, adding nutrients may not increase productivity (Everhart and Youngs 1981).

Secondary Beneficial Effects of Fertilizers

Beyond the primary benefit of enhancing productivity throughout the food chain, fertilizing lakes and ponds yields the following secondary benefits:

(1) Turbidity. Inorganic fertilizers may cause clay particles to settle out of muddy ponds (Swingle 1947).

(2) Interference With Sunfish Nests. Adding fertilizer may stimulate the growth of filamentous algae on the bottom and interfere with the nest building of certain undesirable sunfish populations (Ball 1950, Tanner 1960, Everhart and Youngs 1981).

(3) Fish Embryos. It is possible that applying commercial fertilizers in nesting areas used by spiny-ray fish might cause some of the embryos to die. This might assist in keeping bluegills or other sunfish from becoming overly abundant (Bennett 1962).

Potential Negative Effects of Fertilizer Use

The following are some negative effects from using fertilizers:

(1) Winter-Kill. In Northern States, it is common for fish to suffocate under solid ice cover during severe winters with heavy snowfall. Under these conditions, fertilization and the resulting increase in plankton and plant production may seriously deplete oxygen (Everhart and Youngs 1981). For this reason, fertilization generally is not recommended for Northern States. British Columbia and Alaska, however, have been having some success with fertilization for salmon (see Fertilizing Techniques in this chapter).

(2) Stunted Fish. A danger of fertilization of large bodies of water is that more young will survive, with a possible trend toward a stunted population (Everhart and Youngs 1981).

(3) Summer-Kill. In ponds, an abundance of plankton coinciding with calm, hot weather may result in nocturnal oxygen depletion that can cause a summer-kill of fish (Bennett 1970).

(4) Filamentous Algae Increase in the North. In ponds or lakes in the North, the use of fertilizer to control higher aquatic plants may fail, since it commonly produces filamentous algae instead of planktonic algae.

(5) Algae Bloom. Excessive production of algae, especially filamentous algae, is undesirable in recreation lakes used for boating and swimming.

(6) Upsetting the Food Chain. Fertilization may upset an efficient natural food chain and replace it with one much less efficient. For example, a previously rare algae that is not desirable as food may become predominant over more desirable forms.

Fertilizing Techniques

Dry Fallow of Drainable Basins

When a lake is drained and the bottom is allowed to dry out and crack (plowing may help), an abundance of oxygen becomes available. This results in increased decomposition, compaction of sediments, an increase in pH, and the release of various fertilizing elements from organic colloidal systems. In shallow areas, partial winter drawdowns accomplish this. Such winter drawdowns, ranging from 30 to 70 percent of the lake area, also help control overpopulation of forage fish without greatly reducing numbers of the larger fish and while helping to control submerged aquatic vegetation.

Indirect Fertilizing

Adding sulfates, manganous oxide, manganous dioxide, or lime triggers the release of phosphates and other fertilizers from insoluble bonds with iron and other minerals (Henderson 1949, Hasler and Einsele 1948, Bennett 1970).

Direct Fertilizing

Fertilizing can be accomplished with organic and inorganic fertilizers. While organic fertilizers, such as manure, fodder, or cottonseed meal, do increase fish production, they are likely to create unsightly pond scums and encourage filamentous algal growth (Bennett 1970). Inorganic fertilizers encourage the production of more desirable plankton and are generally preferred.

Direct fertilization methods vary throughout the country, depending upon climate, soil, and water conditions. As a general fish management technique, fertilizing lakes is not recommended outside of the Southeastern United States (Bennett 1970). Some techniques commonly used in this region are discussed below.

In the Southeast, good results are achieved by applying 1,000 to 4,000 pounds of agricultural lime per acre in waters with total hardness of less than 15 ppm. This also applies to treatments using 45 pounds of hydrated lime per acre, hydrated lime being much more water-soluble than agricultural limestone, with the calcium becoming available almost immediately. Other effects of hydrated lime are temporary and last only 6 to 8 weeks (U.S. Department of Agriculture, Soil Conservation Service 1982a). About 2 tons per acre of agricultural lime are required to raise the pH 1 point (as from 5.5 to 6.5). Acid sites should be treated with lime about every 3 years (U.S. Department of Agriculture, Soil Conservation Service 1982a). It also has been found that after treatment with lime, ponds previously treated with nitrogen-phosphorous-potassium (N-P-K) fertilizers (with poor results) produced good plankton blooms. Liming is also recommended for unproductive, acidic, highly colored bog lakes. However, one study found that liming bog lakes had little beneficial effects on brook trout survival (Kretser and Colquhoun 1984). There may also be benefits of using

lime to eliminate fish parasites and other harmful organisms. For best results, lime applications should be followed by adding N-P-K fertilizer. However, lime and phosphate should not be added at the same time, for the lime will precipitate phosphorus (U.S. Department of Agriculture, Soil Conservation Service 1981).

Nitrogen and phosphorus are normally the limiting nutrient elements in most fresh water lakes and ponds, with phosphorus the critical factor in most cases. In some cases, phosphate fertilization alone is adequate. However, nitrogen encourages early spring blooms of plankton and should be included in the first two or three fertilizer applications. After 3 to 5 years of fertilization, the use of 40 pounds per acre of superphosphate is recommended. Also, sandy-bottomed ponds are often deficient in potassium and will respond markedly when this element is added (Bennett 1962).

For general fertilization projects where adequate water and soil analysis data are not available, use complete (N-P-K) fertilizers. Authorities generally recommend an N-P-K breakdown or equivalent of 8-8-2 at 112 kg/ha surface (100 lbs/surface acre 20-20-5 at 45 kg/ha surface (40 lbs/surface area 8 to 12 times per year (or as necessary). Some States, such as Kentucky, are now using superphosphate. The fertilizer can be distributed by boat or from platforms built just under the water surface. The fertilizer should be added at approximately 2- to 5-week intervals until a plankton bloom is dense enough to obscure a white disc 12 to 18 inches below the water surface, with applications repeated only as needed to maintain the "bloom." If applications are not repeated, the water will clear, the fertilizer will become available to rooted plants, and a serious weed problem may develop (Soil Conservation Service).

The Alaska Department of Fish and Game (1979) has developed "Lake Fertilization Guidelines" for lake enrichment programs designed for salmon enhancement in Alaskan lakes. The guidelines include a policy statement, lake selection criteria and feasibility studies, a prefertilization study, a fertilization phase and study, and a postfertilization study. Fertilizing lakes for salmon is still an experimental enhancement technique.

ACIDIFIED LAKES

Acid water is a recognized problem in freshwater fisheries. "Liming" such waters by adding calcium carbonate or calcium oxide can restore many species and lake processes to normal in 1 to 4 years, though to remain effective it must be repeated every 3 to 6 years. Svererdrup and Bjerle (1983) concluded that the dissolution of lime from the littoral and benthic zones of lakes proceeds very slowly and stops after 2 years. In acid lakes that have lost their fish population, Swedish liming projects have demonstrated both successful natural reinvasion from adjoining lakes (Alenas et al. 1981) and successful restocking (Hultberg and Anderson 1982).

Neutralizing surface waters is a feasible technique, but it is not a cure. Resource managers also must consider that the effects of acidification on fish may not be just a function of low pH, but also may result from elevated concentrations of aluminum associated with low pH that are toxic to fish (Baker and Schofield 1982). The effects of lake neutralization on aquatic ecosystems are still poorly known (General Research Corp. 1982). Indeed, neutralization must be considered an experimental rather than a general fisheries technique. Further information on neutralization can be found in "Proceedings of a Symposium on Mitigation Techniques for Acidified Surface Waters," 1984, Fisheries, American Fisheries Society 9(1):2-47.

AERATION--WINTER-KILL

In northern lakes, many techniques have been used in attempts to provide relief from potential winter-kill conditions caused by lack of oxygen. While most have failed (Wirth 1970), destratification and hypolimnetic aeration techniques generally have been effective (Fast 1973, Schierholz et al. 1976, Smith et al. 1975). Destratification techniques can be approached in the following two ways:

(1) Before ice forms, destratification can be implemented to increase the lake's oxygen reserve and reduce the amount of decomposable organic matter (Fast 1973).

(2) During ice formation, destratification equipment can be used to maintain large holes in the ice that will facilitate surface aeration and provide mixing currents to circulate oxygen throughout the water mass (Wirth 1970).

Chapter 3
Wetland Habitat Improvement

INTRODUCTION

Wetlands provide habitat for many wildlife species, but most wetland management is directed toward waterfowl. Waterfowl management has two aspects: management of breeding and brood-rearing habitat for increased production, and management to attract birds during migration and winter. Efforts aimed at one goal may achieve both while benefiting other wildlife species. Perhaps the two most comprehensive manuals available on wetland management techniques are Linde (1969) and Atlantic Waterfowl Council (1972).

AREAS WITH WATER-LEVEL CONTROL

Type of Impoundments

Greentree Reservoirs

Greentree reservoirs are bottomland hardwood areas shallowly flooded for short periods during the dormant growth period to attract waterfowl (Figure 3-1). Short-term flooding makes possible attractive feeding conditions on mast from various oaks supplemented by understory food plants such as wild millet and smartweed. Water depth in greentree reservoirs is about 12 to 18 inches, with narrow ridges remaining dry.

The acorn is the staple wildlife food for which such areas are managed. Ducks (mallard and wood ducks) are the principal target species, but greentree reservoirs are also good for turkey, squirrel, deer, quail, raccoon, other furbearers, and many species of nongame mammals, birds, reptiles, amphibians, and fish.

Site Selection. The area selected for building a greentree reservoir should be flat, contain impervious clay soils, and be close to a low-gradient stream not exceeding a fall of 1 foot per mile to prevent excessive diking costs. Factors to consider in selecting the size include potential hunting pressure, supply of ducks, access, and availability of personnel for enforcement, operation, and maintenance. Unless the reservoir has good road access, with parking areas or water transportation to remote sections, several smaller reservoirs are better than a single large one.

The site selected must have mast-bearing oak timber that can be flooded and that is adapted to flooding. The opportunity for this appears to be limited strictly to broad, geologically old-age

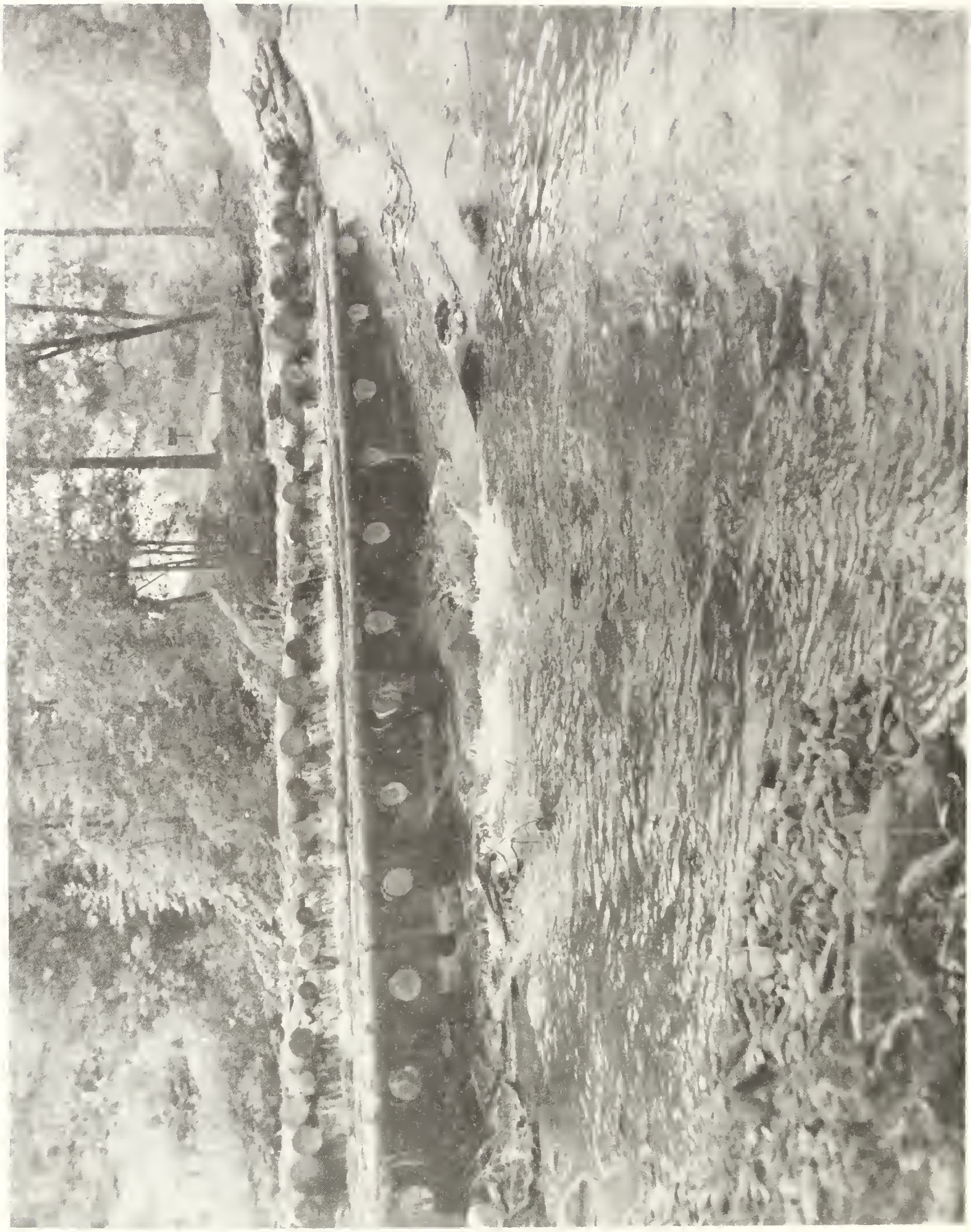


Figure 3-1. Greentree reservoir.

valleys of the south-central and southeastern United States. In years of poor acorn production, mast producers such as blackgum, sweetgum, hickories, and bald cypress also may become valuable sources of food for ducks. Following are species of trees according to their food-producing value for waterfowl:

BEST	GOOD	POOR
Water oak	Cow oak	Elm
Willow oak	Swamp chestnut oak	Ash
Nuttall oak	Swamp white oak	Sycamore
Cherrybark oak	Overcup oak	Yellow poplar
Pin oak	Blackgum	Beech
	Sweetgum	Birch
	Hackberry	Soft maple
	Black locust	Boxelder
	Honey locust	Pine
	Cypress	
	Tupelo	
	Water locust	

Construction Standards. Potential greentree reservoirs need technical engineering, guidance, and planning. Before construction, a detailed plan involving the flooded area, proposed water levels, collecting and evaluating soil samples, and location and design of levees and diversion channels or dams must be outlined and approved. Engineering features that should be planned in detail before construction include the following:

(1) Levees. Levees should be wide enough for small vehicles (Figure 3-2) and seeded or sodded to permanent vegetative cover (include wildlife foods in seed mixture).

(2) Borrow Areas. Borrow areas should be outside the greentree reservoir, preferably on high ground where the spillway is located. Borrowing from within the greentree reservoir reduces the size of the reservoir and creates a deep-water hazard for hunters.

(3) Spillways and Drainage. The borrow area, if properly located, may be incorporated into the spillway, which should flow onto undisturbed earth. When a system of levees and dikes is needed to make flooding possible or to divide large areas into smaller units, the spillway should be incorporated into the structures (Figure 3-3). Stop logs and radial gates, which can regulate both inflow and outflow, are the most efficient water control structures (Hunter 1978).

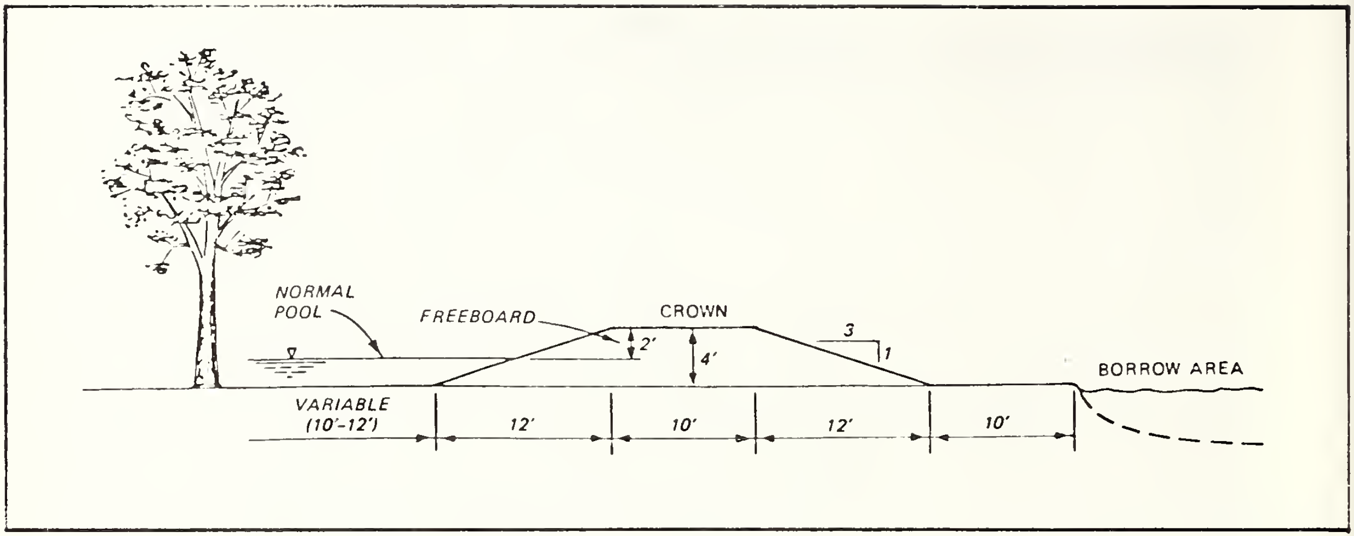


Figure 3-2. Recommended levee dimensions for a greentree reservoir.

Source: Mitchell and Newling (in press)

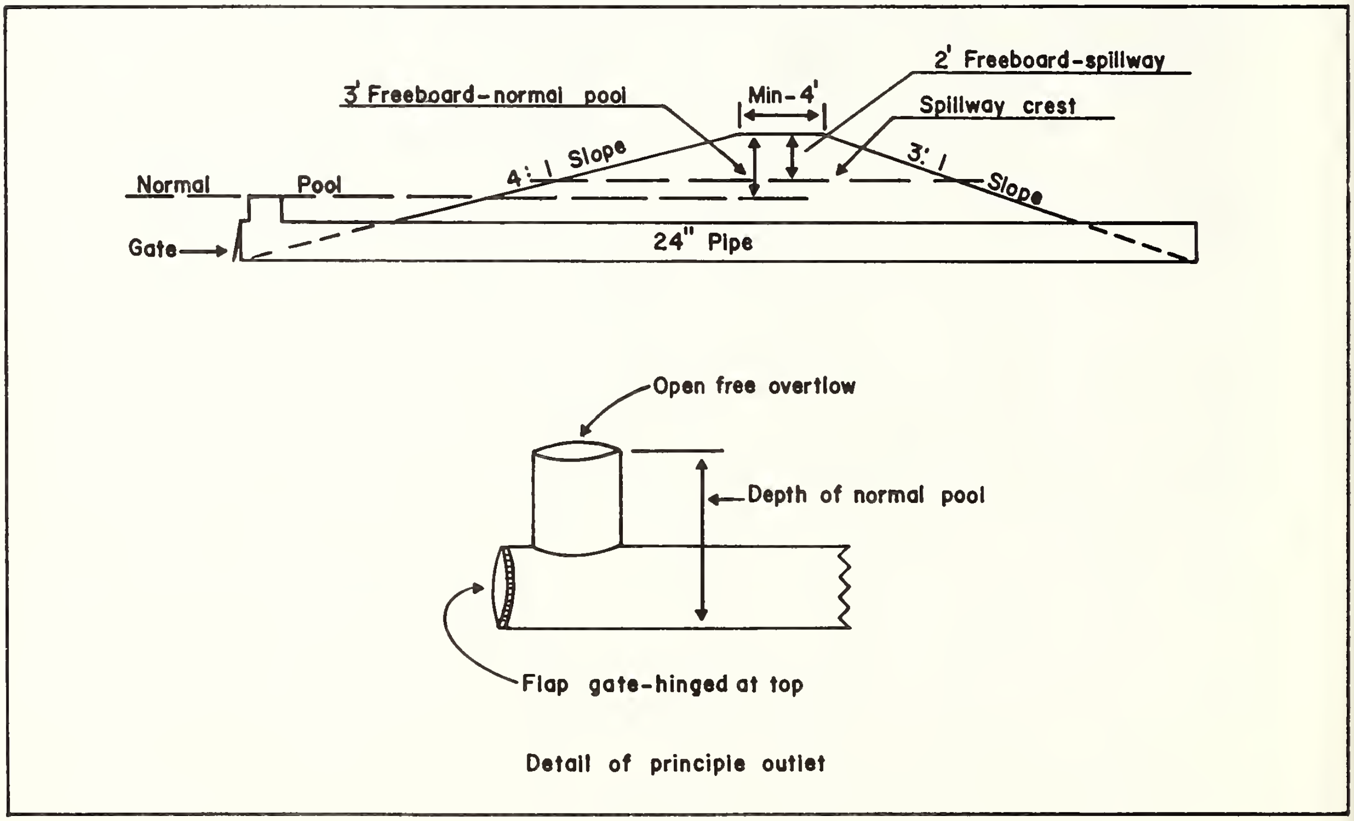


Figure 3-3. Greentree reservoir--levee, drain, and primary spillway.

Flooding Greentree Reservoirs. Several methods involving low-contour levees with control structures can be used to flood greentree reservoirs.

(1) Retention of Rainfall or Floodwaters. Floodwater or rainwater retention requires minimum investment and is economical to operate. This method, which depends on rainfall for flooding at the proper season, is best adapted to flat bottoms with low gradients. Because soils on these sites generally are heavy clay and difficult to drain, sites should be selected that will allow the impoundment to be drained early in the spring to prevent losses in tree growth.

(2) Diversion of Inflowing Streams. This method, which consists of a gate-type structure that allows a stream's water to be diverted into the diked area at the proper time, may be used where small streams enter terraces and well-drained bottomlands. Initial cost is governed largely by size of the diversion structure and the extent of facilitating levees.

(3) Pumping. Pumping is used where groundwater is readily available and where other water sources are unreliable. Flooding is completely controlled but requires a relatively fixed annual cost for pumping.

Water Manipulation in Greentree Reservoirs. Areas in which hardwood bottoms are being regenerated under even-aged management should be withheld from flooding for 2 years to allow trees to become established. Flooding should take place in the fall with leaf color changes, a period that usually requires 6 to 8 weeks to complete (Mitchell and Newling in press). Water should be removed in the late winter or early spring before the growing season begins. In the South, the flooding period is from early October to late February, and in more northern States, late September to mid-April (Rudolph and Hunter 1964, Atlantic Waterfowl Council 1972). Because only a few inches of water or saturated ground during the growing season can cause permanent timber damage within one or two seasons, thorough draining is essential (Hunter 1978).

Where wildlife compete strongly for mast, water levels should be lowered periodically to prevent the premature depletion of mast (Rudolph and Hunter 1964). If a reservoir has heavy duck concentrations during the fall, it should be flooded gradually to prevent ducks from depleting acorns too early (Hunter 1978). On large reservoirs with excessive depths, water levels can be increased in stages, making available mast that might otherwise have been too deep for dabbling ducks. Ducks also are attracted to the feather-edge of slowly rising water (Hunter 1978).

Timber Management In Greentree Reservoirs. Annual flooding of dormant timber eventually may increase soil moisture, causing the forest community to convert to vegetation characteristic of wetter habitats (Newling 1981). If that is undesirable and if several greentree reservoirs exist in the system, flooding should be alternated so that each winter at least one impoundment is left unflooded and can dry out.

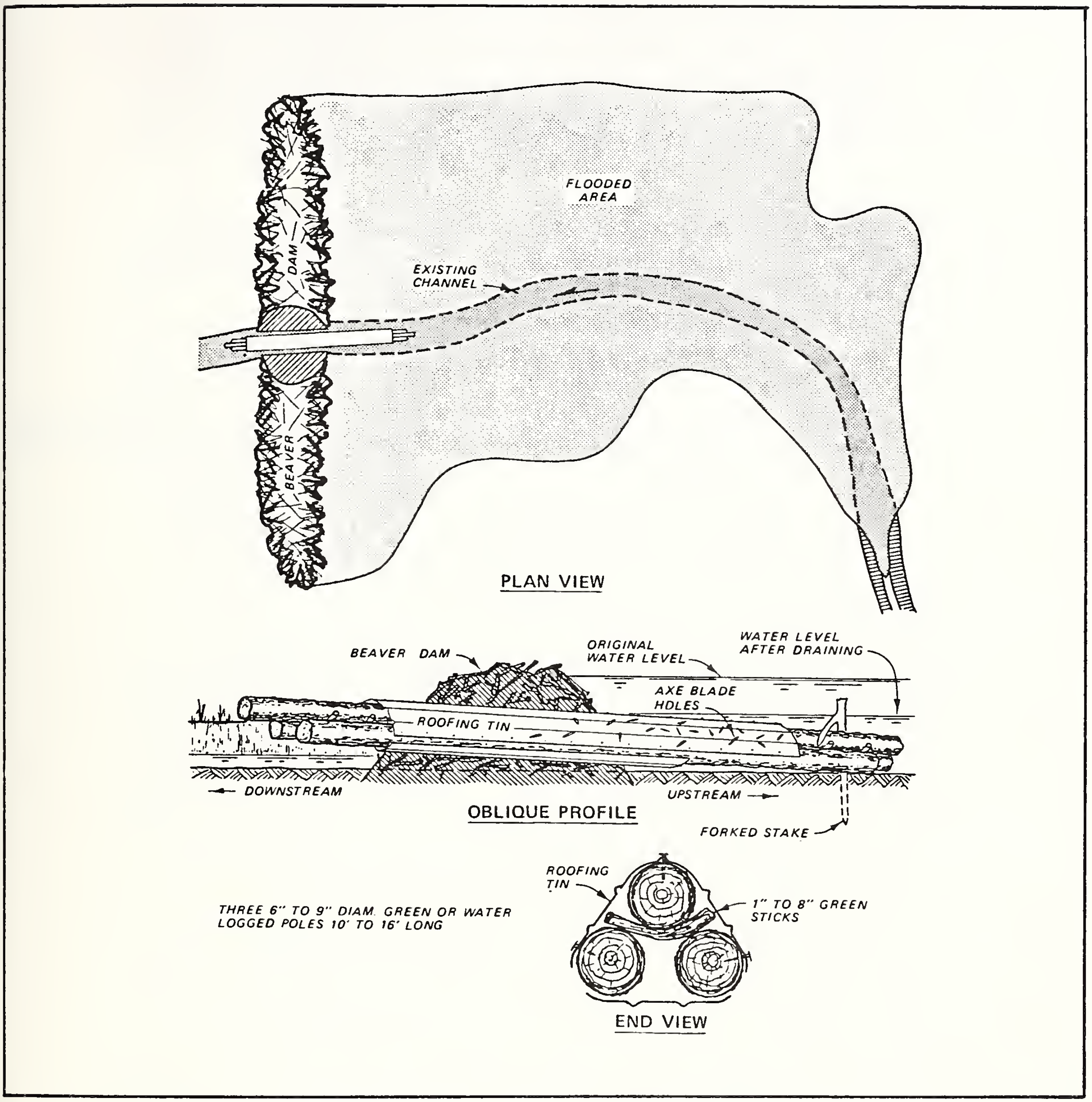
On a greentree reservoir, 70 percent of the timber can be retained in mast production under a 100-year rotation (Mitchell and Newling in press). Regeneration cuts may vary from 1 to 15 acres. To allow time for regeneration, cuts are made before the growing season. Intermediate cuts may be made in 20- and 30-year-old stands and should result in a residual stand of 60 to 70 square feet of basal area, a density that produces a crown development that is conducive to maximum mast production and volume growth. Only areas scheduled for regeneration cuts should be flooded. Because an open marsh supplements a greentree reservoir by increasing habitat variety and nesting and brood-rearing areas, openings of 2 to 5 acres should be created if possible during regeneration cuts.

Beaver Ponds

Partially drained beaver ponds planted with grain make attractive waterfowl areas. Beaver ponds should have road access, and when water is removed, it is necessary to leave an area of at least 1 acre of exposed mud. For ducks, mudflats should be seeded with Japanese millet or other species and reflooded 2 to 30 inches deep. This process can be done as follows:

(1) Drain the pond by notching the dam with the adz side of a mattock. This should be done at the main channel by cutting about halfway from the base to the top of the dam's downstream side without causing a waterflow (Arner 1963) (Figure 3-4). Then, once this is done, make a break at the top to start the water flowing, using the mattock and the force of the rushing water to make a deep, narrow V to accommodate a three-log drain (Arner 1963). (To allow ample time for draining the pond and completing work before nightfall, work should begin in the morning; otherwise, the beaver will repair the dam at night, submerging partially completed work.)

(2) After the waterflow has slowed and the area to be planted has been exposed, install the three-log drain, ensuring that the drain's upstream end is securely fastened to keep it under water and holding the logs together with two sheets of roofing tin 2-1/2 by 8 feet and about 1 pound of 10d nails.



Construction and placement details for a 3-log drain used for draining beaver ponds.

Figure 3-4. Beaver pond drain.

Source: Arner 1963

(3) As soon as the mud flats are exposed and the mud is about ankle deep, plant millet at the rate of 20 pounds per acre. Two varieties of Japanese millet are recommended: chiwapa, and frumentacea, which is best because it matures faster (45 to 65 days) and yields more (2,100 pounds per acre) (Martin in press). Also, late draining and planting will maintain the pond as brood habitat and reduce weeds.

(4) When the millet is established, reflood the pond until the water level is one-quarter to one-half the height of the plant. If army worms (moth family Noctuidae) are a problem, incremental flooding may create a barrier for them and reduce damage.

(5) Once the millet is mature, remove the three-log drain so that beaver can reflood the pond to its original depth (Martin in press). To maintain specific water levels and natural vegetation in beaver impoundments, install beaver pipes (Laramie 1963, 1978), each pipe being a 24-foot-long, 12-inch square wooden tube with one solid end and a bottom of 2- by 4-inch wire mesh, built in two sections. Secure pipes by steel posts. Up to three pipes can be used, each able to handle normal runoff from a 3.4 square mile drainage area.

Shallow Marshes

On brackish or freshwater marshes, artificial impoundments may be used to improve existing marshes or create new ones. For maximum use by puddle ducks, 75 percent of the area should be about 18 to 24 inches deep (Linde 1969); for coots, diving ducks, beaver, and otter, water should be deeper, but shallower for many other species. Pumps, tides, and gravity can be used to put the water on the area and take it off, although tides and gravity require some sort of control structure as described in the Free Overflow or Straight Drop Spillway section of this chapter.

Most brackish marshes have heavy growths of needlegrass rush and cordgrass undesirable for ducks. They thrive with daily tide changes but are killed with constant water levels. Such marshes can be made into excellent, easy-to-manage duckponds at reasonable cost. In managing such ponds, the water level and salt content should be controlled to favor widgeongrass or other desirable plants (Davison and Neely 1959). An area should be selected that can be enclosed by a dike and can be flooded at least 2 feet deep. If possible, the dike should not cross tidal creeks, runs, or sloughs that have soft, difficult-to-fill bottoms. One type of control structure for brackish marshes is an asphalt-coated corrugated metal pipe that goes through the dike and is attached to a riser with flashboards to control the water depth. When using this control structure, the flashboards should be set at normal high-tide level. When the pond water becomes too fresh, as shown by

growth of fresh-water vegetation, poor growth of saltwater species, or by a testing device, the top board should be removed for 3 to 4 weeks to increase its saltiness. If tidal fluctuations are inadequate, a pump should be used to recharge salinity. To protect the pond against storm tides by allowing the water level inside the pond to fluctuate with the level outside, the use of a wide spillway inside the dike is suggested.

To ensure that some impoundments will have water while others are being drained, a series of smaller impoundments is better than a single large one. To accomplish this, a system of dikes to separate impoundments should be installed, perhaps with levees to prevent roads and nonproject land from being flooded. Typically, impoundments are connected by control structures in the dikes, with dikes and levees serving as roads.

Impoundment Construction

Impounding waters in shallow marshes on greentree reservoirs requires the construction of dikes and levees and the selection of a control system.

Site Selection

Considerations for site selection include the area's location within the State or flyway (and therefore its relation to migration flights, breeding ranges, and wintering grounds), as well as its topography, soil type and productivity, water supply and quality, vegetation, and accessibility. The Atlantic Waterfowl Council (1959) has presented methods to survey marsh sites, but the designs of such sites must be prepared by professional engineers.

(1) Water. In general, the normal water elevation should be established at a height where at least 75 percent of the marsh basin will be flooded by water less than 2 feet deep (Atlantic Waterfowl Council 1959). Then, the peak runoff of the watershed should be computed (Atlantic Waterfowl Council 1972), the marsh structures should be designed to contain this runoff, and the cost of the project should be planned. To adequately fill 91 acres of marsh generally requires a watershed of 40 acres of woodland or 30 acres of pastureland, or 20 acres of cropland (Atlantic Waterfowl Council 1959). When seepage is minimal, a flow of 8 to 15 gallons per minute is generally enough to maintain a 1-acre pond in the eastern United States (Addy and MacNamara 1948). For specific information on these matters, contact the U.S. Geological Survey, U.S. Soil Conservation Service, or your State hydrologic bureau. For information on rainfall and evaporation, consult the weather bureau. Avoid sites likely to be polluted from watershed runoff.

(2) Soils. Plants are good indicators of soil quality. For example, softstem bulrush and burreed usually indicate high fertility, while black spruce, leatherleaf, and sphagnum indicate low fertility (Linde 1969). The Atlantic Waterfowl Council (1972) lists some other good plant indicators for salinity, marsh depth, and pH. Highly acidic waters (pH 5.0 and below) with an alkalinity of 10 ppm usually are unproductive (Linde 1969). If bog mats are present, they may float with flooding. This reduces the open water area and value of the impoundment unless bog mats are small enough to be used as nesting islands. Sites should be rejected where organic soils comprise most of the basin (Atlantic Waterfowl Council 1959). Consult with the Forest soil scientist or the local Soil Conservation Service soil scientist concerning suitability of soils in the basins beneath the dike and at the outlet.

(3) Vegetative Cover. Agricultural lands are the best choice for construction of shallow marshes, followed by grasslands and brushy areas. Watersheds without cover will produce undesirable silt-laden water after each storm.

(4) Topography. The impoundment basin should be as flat as possible, with a gradient less than 1 percent, so that up to 75 percent can be flooded with water less than 2 feet deep. Flat, shallow water impoundments are the cheapest to control. Ideally, the flat area should have gentle, undulating surfaces to provide islands, diverse water depths, and an irregular shoreline for edge effect.

(5) Exposure. If wave erosion is a problem, dikes should be established so that prevailing winds cut across the impoundment. A band of dense, emergent aquatic plants can be established along and below the water line; above the water line, riprap or vegetation with a good root system can retard erosion by waves, wind, or muskrat burrowing.

(6) Tides. In designing marsh improvement facilities, consider normal tide fluctuations and abnormal tides caused by weather disturbances. Historical information on normal and abnormal tide fluctuations for most areas can be obtained from the U.S. Army Corps of Engineers' Regional Office.

Dikes and Levees

Dikes separate impoundments, while levees prevent water from flooding nonproject land. Construction methods for the two are essentially the same:

(1) Dikes should be no higher than 10 feet unless detailed soil studies are conducted. With or without such studies, the services of an engineer should be considered.

(2) Tops should be gravelled and at least 10 feet wide to facilitate travel by maintenance vehicles, or 20 feet for two-lane travel.

(3) Slopes should be 3:1 or 4:1. (A 4:1 slope, with its wider base, deters muskrat burrowing.)

(4) Freeboard should be sufficient to keep waves from a maximum velocity wind from overtopping the dike at the maximum flood stage.

(5) For inexperienced equipment operators, a batter-board (Figure 3-5) is recommended to guide slope construction.

Construction of Dikes and Levees. Heavy equipment used usually involves a front-end loader, dump truck, bulldozer, scraper, dragline, grader, and low-bed tractor-trailer to transport tracked equipment. Following are recommended construction steps:

(1) Use the dozer to remove rocks and stumps from the dike area.

(2) Use the dragline, or blasting, to dig out the core area.

(3) Bulldoze the core fill, load fill by front-end loader into the dump truck, dump the fill into the core area, and spread and compact it with the dozer. (Special compaction equipment such as a sheepsfoot roller usually is unnecessary). An

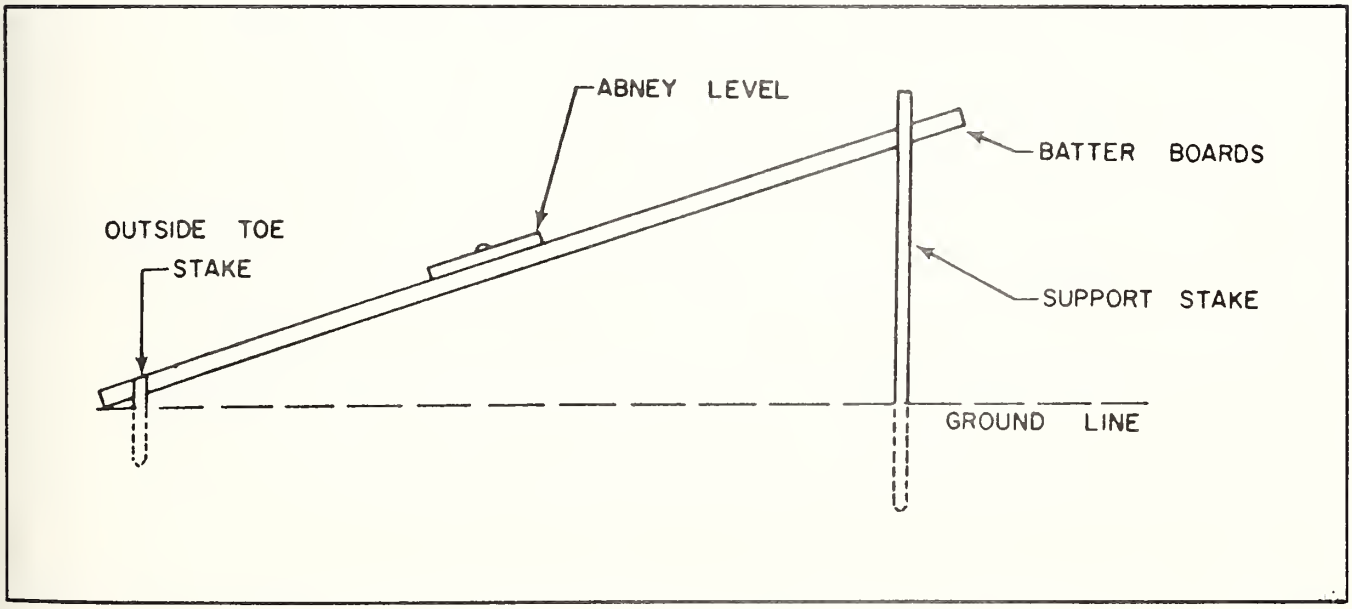


Figure 3-5. Batter-boards for dike slopes.

Source: Atlantic Waterfowl Council 1972, Linde 1969

alternative is to use a scraper pushed or pulled by a dozer to scrape up the core material. Tow the scraper to the core area of the dike where the material is deposited.

(4) When the core is up to grade level and properly sloped, place a dragline on the dike to pull in onsite material for the outer surface, or have a dump truck bring in fill from a borrow pit to be spread by the dozer and smoothed by the grader.

(5) If the dragline is used, pull in onsite fill, place it on the slopes, allow it to dry, and then drag the slopes using a 1-by-1-by-4-foot wooden drag for smoothing and leveling.

(6) After about 6 months, disk the slopes (at least 3.5:1) with a small dozer with wide treads and prepare for planting. On a dike with light traffic, no surfacing is needed; cover the core with topsoil and plant to develop a heavy sod. Otherwise, 6 to 12 inches of surfacing material will suffice. On single-lane dikes, turn out points should be constructed every 300 yards.

Types of Dikes and Levees. Following are several types of dikes and embankments.

(1) Simple Embankments. These consist of uniform material throughout (Figure 3-6). Where onsite soil must be used, normally a dragline is used.

(2) Core. These have a core of the least-pervious material, usually clay, with the outer surface of onsite soil (Figure 3-7). After the dike area has been cleared of debris, a dragline or blasting can be used to excavate a core trench 3 to 4 feet wide down to solid inorganic subsoil the length of the dike. Add the core in layers and, as filling proceeds, compact it with heavy equipment. Surface soil usually is brought in from borrow pits in high ground at either side of the dike and applied in 6- to 12-inch layers compacted by the equipment.

(3) Diaphragm Dikes. These dikes have a thin section of concrete, steel, or wood that acts as a barrier to percolating water (Figure 3-8). In a full diaphragm dike, the barrier extends from the level of the impounded water into an impervious foundation. In a partial diaphragm dike, the barrier does not extend into the impervious foundation.

(4) Sand Dikes. Sand dikes are used to prevent storm tides from moving ocean water into marshes. Where existing dunes are too close to the ocean or too eroded to effectively protect marshland, consider using bulldozers to develop dunes 6 to 8 feet high and sloped 1:10 to 1:20 on the ocean side, 150 to 250 feet from mean high tide. Where few or no dunes exist, a

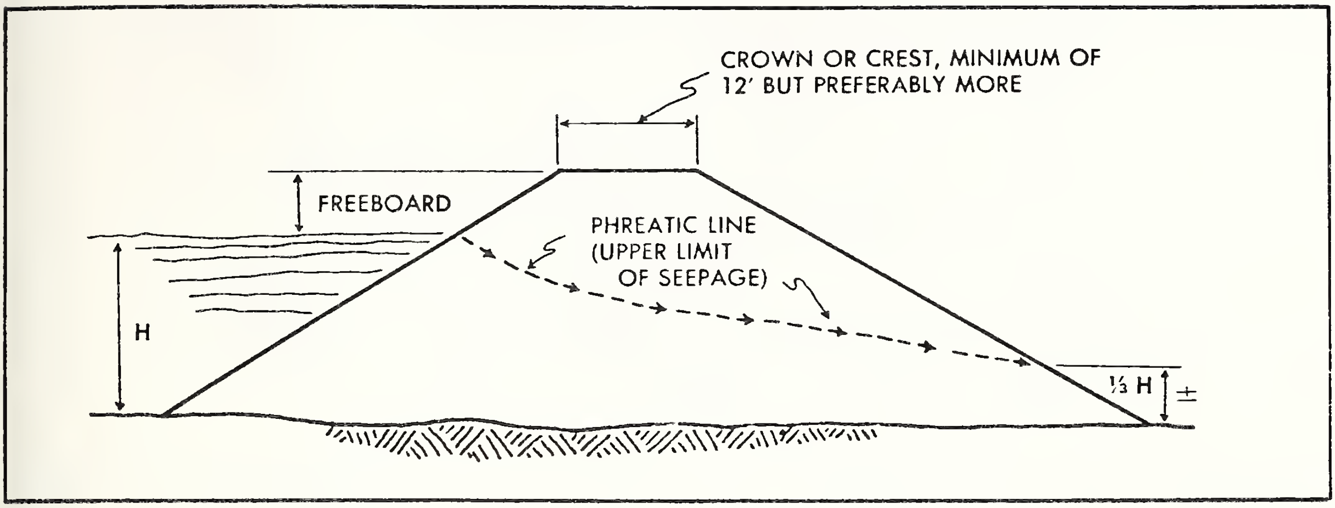


Figure 3-6. Plans for constructing a typical homogenous fill dike.

Source: Atlantic Waterfowl Council 1972

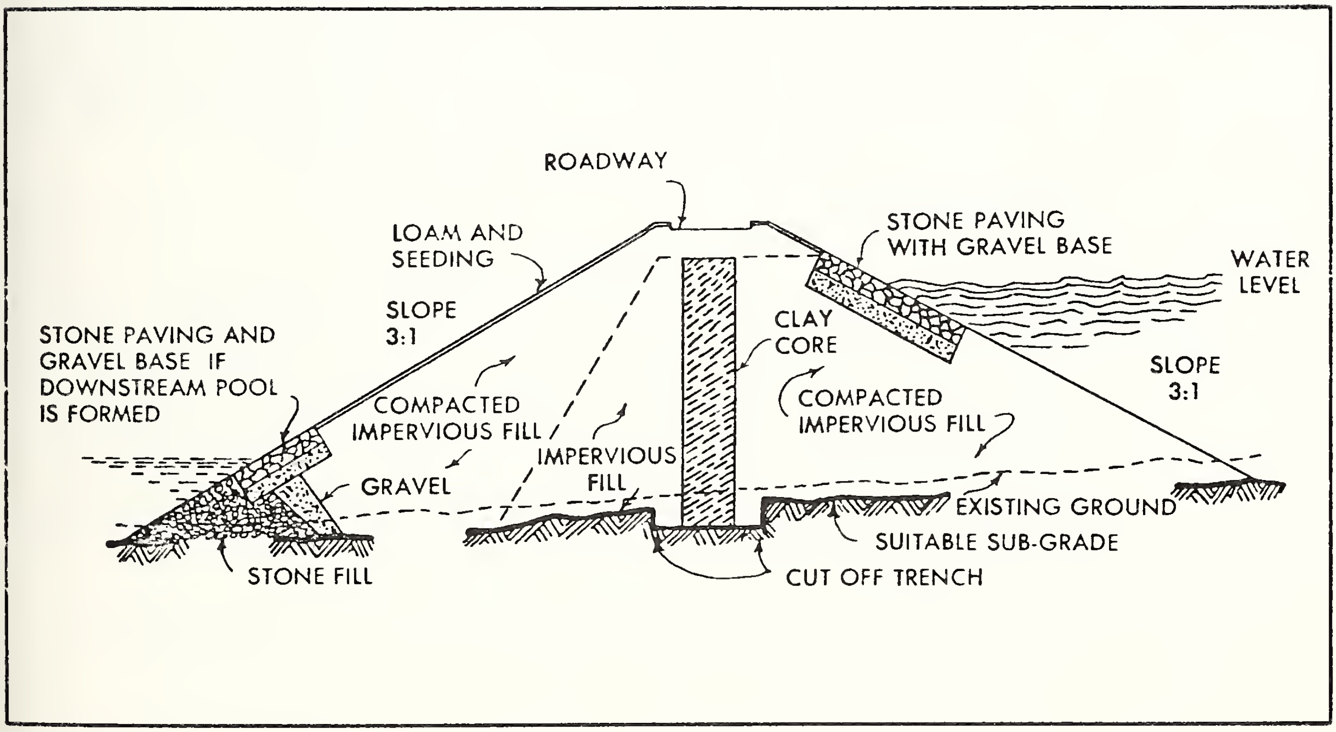


Figure 3-7. Plans for construction of a typical clay core dam.

Source: Atlantic Waterfowl Council 1972

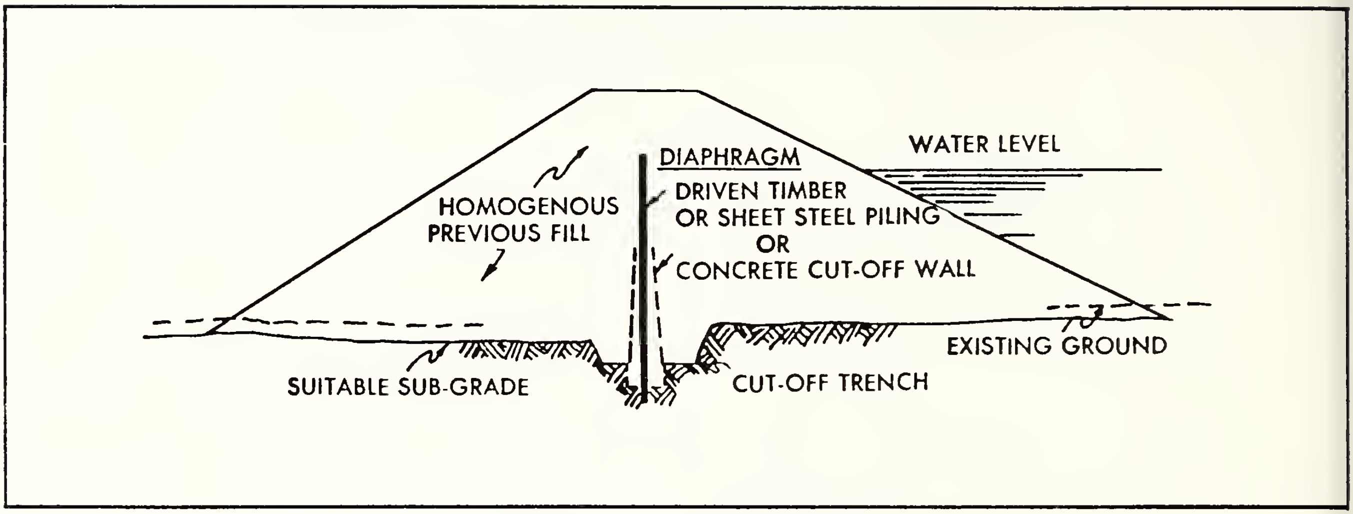


Figure 3-8. Plans for construction of a typical diaphragm embankment.

Source: Atlantic Waterfowl Council 1972

snow fence can be stretched 250 feet from mean high tide, with posts 8 feet apart on alternate sides. The fence will be covered in a few months with fine sand, and later with coarse sand. To stabilize the dune, native beach grasses should be planted by hand or mechanical planter 12 inches apart in rows 28 inches apart as soon as bulldozing is completed or after sand fencing has received an 80 percent buildup.

Control Structures

A basin that impounds runoff water or streamflow needs an emergency spillway to dispose of flood waters (Figures 3-9 and 3-10). Small marsh impoundments need spillways that can handle the peak flow expected in a 50-year flood. This peak flow can be determined from stream flow records or calculated (Atlantic Waterfowl Council 1959). Information on stream flow levels is available from the district Soil Conservation Service office, the Army Corps of Engineers, the U.S. Geological Survey, and/or the Federal Emergency Management Administration, depending on which agency has collected data on a particular stream.

One of two equations is used to determine emergency spillway size (Linde 1969, Atlantic Waterfowl Council 1972):

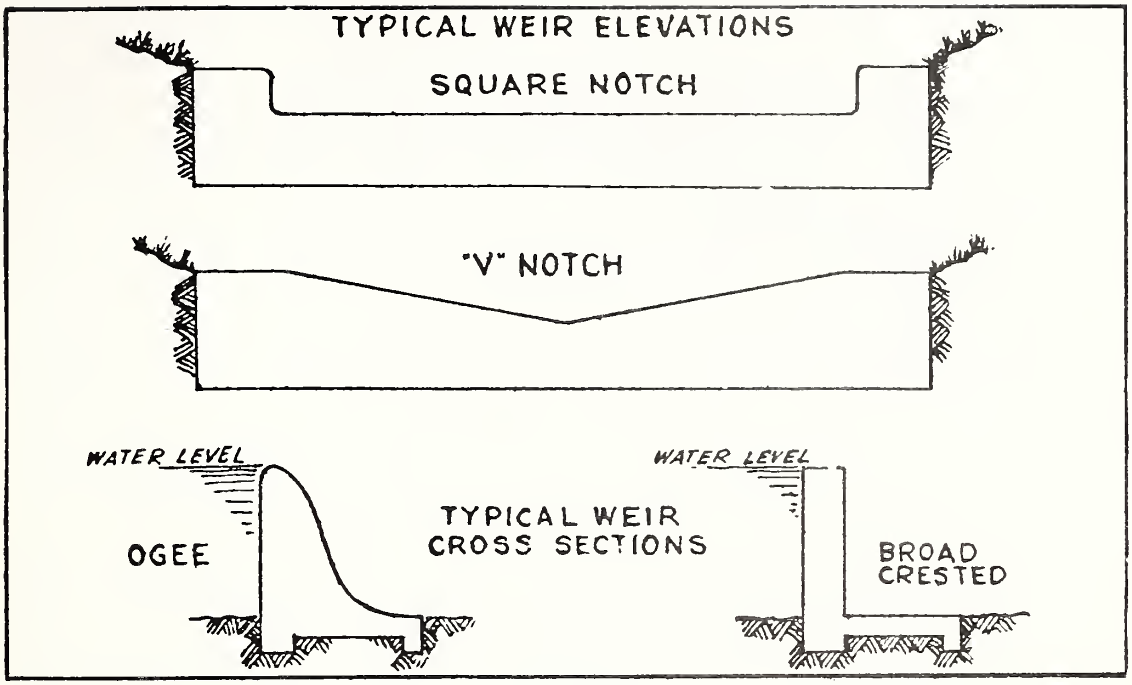


Figure 3-9. Concrete weir spillways.

Source: Atlantic Waterfowl Council 1972

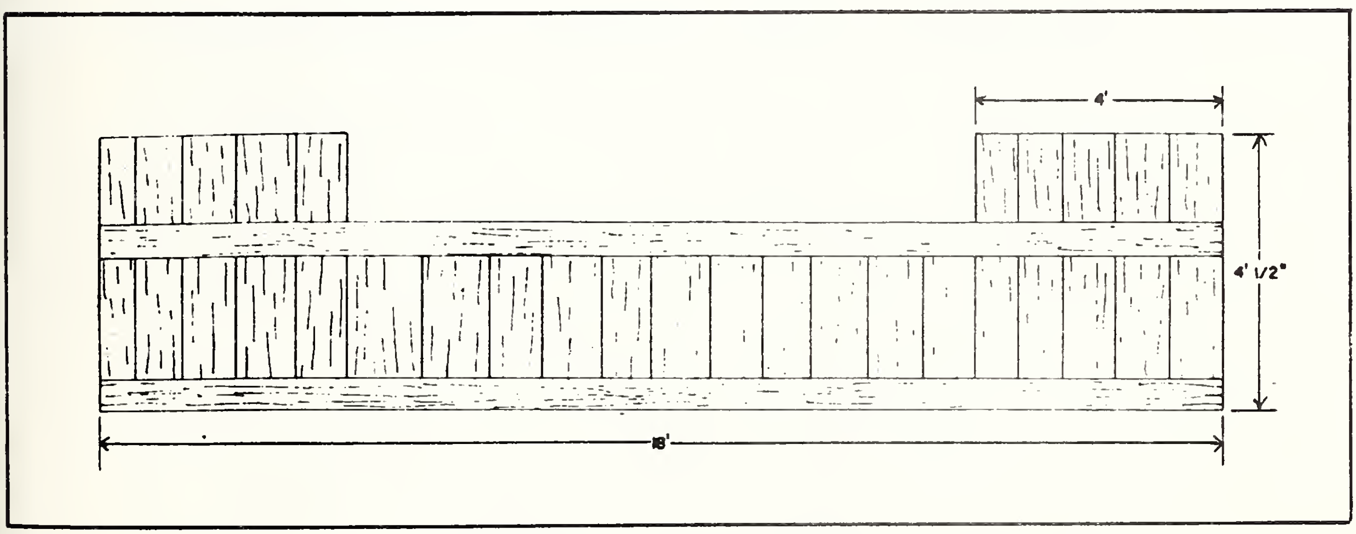


Figure 3-10. Wooden spillway.

Source: Atlantic Waterfowl Council 1972

(1) $L = \frac{R}{(CH)3/2}$,

where

L = length of spillway in feet.
R = rate of flow of the watershed in cubic feet per second.
H = depth of spillway (in feet).
C = a coefficient--
when H = 0.5 feet, C = 2.70;
when H = 0.75 feet, C = 2.67;
when H = 1.00-2.5 feet, C = 2.63

(2) $R = \frac{(WDL)\ a}{T}$,

where

R = rate of flow in cubic feet per second.
W = average width of stream (in feet).
D = average depth of stream (in feet).
L = length of stream portion over which speed of floating chips was measured.
T = time in seconds required for chips to travel (L) distance.
a = a coefficient varying with stream bottom: when stream bottom is rough, strewn with rocks or coarse gravel, a = 0.8; when bottom is smooth (mud, sand hardpan, bedrock), a = 0.9.

The top of the dike should be at least 12 inches above the maximum water depth expected to flow through the emergency spillway under peak flood conditions. Usually, a good location for the spillway is near the end of the dike where the natural terrain approaches the dike level. Control structures for draining the impoundment often are incorporated into the spillway. To prevent washout, riprapping often is necessary around the exit and entrance of the control structure. Stone usually is used. Cement or burlap bags filled with eight parts gravel to one part cement, and wetted down after each layer is placed, may also be used. These bags stay in place better than stone and are durable. There are many types, styles, sizes, and combinations of control structures.

Free Overflow or Straight Drop Spillway. This type is used most often in the northeastern United States in low head design, common to most large shallow area impoundments (see Figure 3-9). The free overfall spillway of reinforced concrete or wood planking usually is designed for fixed water level impoundments. In low head waterfowl impoundments, the design generally is modified to provide for drawdown or limited increase in storage capacity. To prevent scouring, which will cause structural damage, provide artificial protection below the spill crest. Incorporate a concrete or plank apron with cutoff walls as an integral part of the design to prevent structural damage.

A reinforced concrete spillway usually is the most satisfactory design. The initial cost of concrete design typically is much higher than log cribbing, but maintenance costs are minimal. However, the location of the impoundment site and availability of material may warrant using material other than concrete. The design should provide access for maintenance.

Ogee Spillway. The Ogee spillway, usually designed of reinforced concrete, has an "S" shaped weir, in contrast to the straight overfall type. Water flows over the crest and along the profile of the structure, thereby achieving minimum interference and maximum discharge efficiency. In many low head designs for waterfowl, water storage often is important and the discharge efficiency frequently is a factor that does not limit design. The difficulty of construction and high cost may limit construction of Ogee spillways. When Ogees are used, consideration should be given to incorporating drawdown features.

Natural Spillway. This inexpensive spillway provides for impoundment runoff over natural, undisturbed ground and is used mostly in small freshwater impoundments when runoff capacity, soil type, and vegetative cover are suitable. Maintenance costs may be high. Drawdown or drainage is not possible without modification.

High Tube Overflow. Small impoundments often do not warrant the expense of installing sophisticated control structures. In such cases, a simple overflow tube, which is a horizontal tube large enough to accommodate the expected spill, will suffice (Figures 3-9 and 3-11). The lower edge of the tube should be set at the height of the desired impoundment level; water rising above this point will flow out of the tube. Providing a grass or rock emergency spillway to accommodate excessive spill during flood conditions is wise. The tube can become plugged or it may prove inadequate to handle water from an exceptional storm. No water level manipulations are possible with this type of control. However, if a low drain tube also is installed, pond levels may be lowered or the pond can be drained. This feature is highly desirable for impoundment management.

Capped or Gated Tube. In small impoundments where heads are low, a single low tube can be installed. It is capped from the impoundment side by a flanged wooden plug that fits snugly inside the tube and has a shoulder that fits against the end of the tube.

It is held in place by water pressure from the impoundment side, but water levels must be shallow or it will be difficult to remove the plug to drain the impoundment. A better solution is a header plate welded to the impoundment side of a low tube with a sliding gate installed. The header plate is provided with slopes formed by welding angle irons to the header and is fitted with a steel or plywood gate.

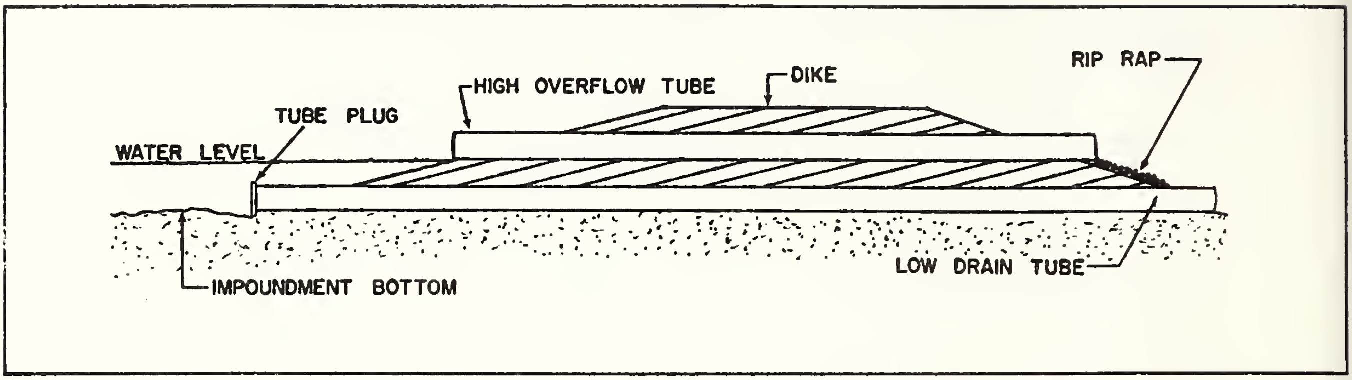


Figure 3-11. Horizontal overflow tube. (Control structures for small impoundments may consist simply of a horizontal overflow tube.)

Source: Linde 1969

Log Crib. The log crib spillway used in wetland impoundment is limited to locations where the use of permanent materials would be too costly. Logs used are best if selected for having uniform taper and resistance to decay. Treating log material with preservatives, such as coal tar creosote or pentachlorophenol, is desirable where longevity of the structure is important.

The abutments and spillway usually are faced with 3-inch treated planking. Maintenance for this inexpensive spillway often is very high. In general, log spillway construction consists of toe piling being driven on the upstream face of a bed log and the spillway having a maximum incline of 30°. Bark from logs not completely underwater should be peeled. It may be desirable to include a stoplog section for drawdown.

Drop Inlet. This is a vertical tube positioned at the desired water level. The lower end is connected to a horizontal tube that discharges through the dike. The vertical tube acts as an overflow tube, which collects excess impoundment water. This type of structure provides no means for water level manipulation. Water levels can be maintained only at or near the level of the overflow tube. During periods of extremely high flow, the inlet cannot be opened wider to remove excess water. When water levels increase, the only means for additional flow is over the emergency spillway. Unless a separate drain tube is provided, there is no way to drain the impoundment.

One form of drop inlet consists of a vertical tube or riser made from a half culvert opened along its length, with the open edges fitted with channels for stoplogs or flashboards. The vertical riser is attached to a horizontal discharge tube at its lower end. The height of the stoplogs in the vertical riser controls the impoundment overflow and water levels. This provides control for

water level manipulations. If all flashboards are removed, the impoundment can be drained.

Tin Whistle. A vertical riser tube is located in the impoundment dike with its bottom end connected to a tube running through the dike. The vertical riser is equipped with stoplog channels along its length. When stoplogs are inserted, they separate the intake (impoundment side) and discharge openings at the bottom, thus forcing the impoundment water to rise up and spill over the stoplogs before it can flow out of the impoundment. The height of the stoplogs thus regulates the water levels in the impoundment.

Because the horizontal tubes are located at the bottom of the impoundment, only bottom water is discharged from this type of structure in contrast to the drop inlet, where surface water is discharged. Because most dissolved substances and nutrients are located near the bottom, a bottom discharge system will remove a large portion of them from the impoundment. If horizontal tubes are deep enough, the impoundment can be drained by removing the stoplogs.

Stoplogs can be replaced by a sliding steel gate operated by a handwheel. The handwheel turns a long screw shaft that raises or lowers the gate. The gate has two sections that slide across each other in such a way that the gate may be opened to allow flow from either above or beneath it. This structure is much easier to operate than the stoplog control, and it allows easier and more precise water level control. Operation is unaffected by heavy flows or flood conditions.

Stoplog (Stop Plank). This is one of the best control structures (Fredrickson and Taylor 1982). It resembles a concrete box lacking top and front panels. The back of the structure is fitted with a corrugated, galvanized-steel drain pipe at the bottom of the back wall. A pipe 18 inches in diameter and long enough to extend through the bottom of the dike generally is adequate for structures draining areas up to 40 acres. The walls and bottom should be at least 5 to 6 inches thick. Each side has a groove toward the inside front edge extending the entire height of the box and capable of accommodating a board (stoplog) 2 inches thick. The sides, as well as the inside front-to-back distance with boards installed, should measure 18 inches. The bottom of the structure extends 6 to 8 inches beyond the front, forming an apron that reduces soil erosion. The bottom should be as flat and level as possible to prevent water seepage when stoplogs are in place. The height of the structure is determined by the maximum water level desired and by the depth of any existing internal borrow ditches. An antiseep collar around the structure may be necessary to control rodents.

Stoplogs of several different widths (height) are useful to enable water-level changes as small as 0.4 inch. To change water level, an appropriately sized board is installed or removed. Size and

number stoplogs so that changes can be made quickly and accurately. The best materials are rough-cut redwood or treated lumber. Shiplapped edges should be used because the wood will warp and the stoplogs will then fit together poorly. If seepage occurs around and between the stoplogs, plastic sheeting should be placed over the pool side of the boards and held in place with thumb tacks or bulletin board push-pins. Lower boards not subject to manipulations should be sealed for minor water-level adjustments with an oil-base caulk. A locking device may be required to prevent tampering. Control structures are ideal sites for attaching water gauges (Fredrickson and Taylor 1982).

Stoplogs with matched lumber and tongue and groove or half laps best reduce leakage. Because stoplog removal is difficult under water pressure, each stoplog often is equipped with a screw eye bolt at each end so that hooks can be used to remove the logs. Place a sheet of 3/4-inch plywood in front of the horizontal tube on the impoundment side of the structure to decrease water pressure as the stop logs are removed.

Gates. Gates are used in larger impoundments that require large concrete structures constructed by engineers. Sliding (lift) gates span horizontally between guide channels in supporting piers. They must be heavy--usually cast iron or steel--and are raised by an overhead hoist device. Roller gate dams have sliding gates equipped with rollers, which bear between the gate surface and its track, to avoid the high lifting pressures required to operate the ordinary sliding gate. Radial gates are large steel gates mounted on control arms. The outer ends of the arms pivot on their mountings so that the gate describes an arc through the radius of the arms as it moves up and down in opening and closing. The edges and bottom of the gate are sealed with heavy rubber flaps forced against the side of the gate channel by water pressure. These gates are extremely heavy and are moved by pull chains fastened to a winch. Radial gates are highly desirable on large impoundments.

Flap Gates. In tidal areas, flap gates can be installed on pipes or headwalls by setting the pipe through the dike on a series of level sleepers (Figure 3-12). In this fashion, the pipe is level, and the headwall is at right angles to the pipe. To drain or flood an area, gates are installed on both ends of the pipe passing through the dike so that when one gate is raised, the force of the water running through the pipe pushes the other gate open to fill or drain the impoundment. Water pressure against the outside of the gate keeps it closed. If runoff water is present in appreciable quantities, the fixed splash board structure on the inside of the impoundment should be used. The flap gate on the outside prevents the tide from entering the impounded area. Gates should be installed so that the inside elevation of the top of the gate coincides with low tide elevations. This will produce the maximum discharge under fluctuating conditions. Deeper installations will only increase the cost.

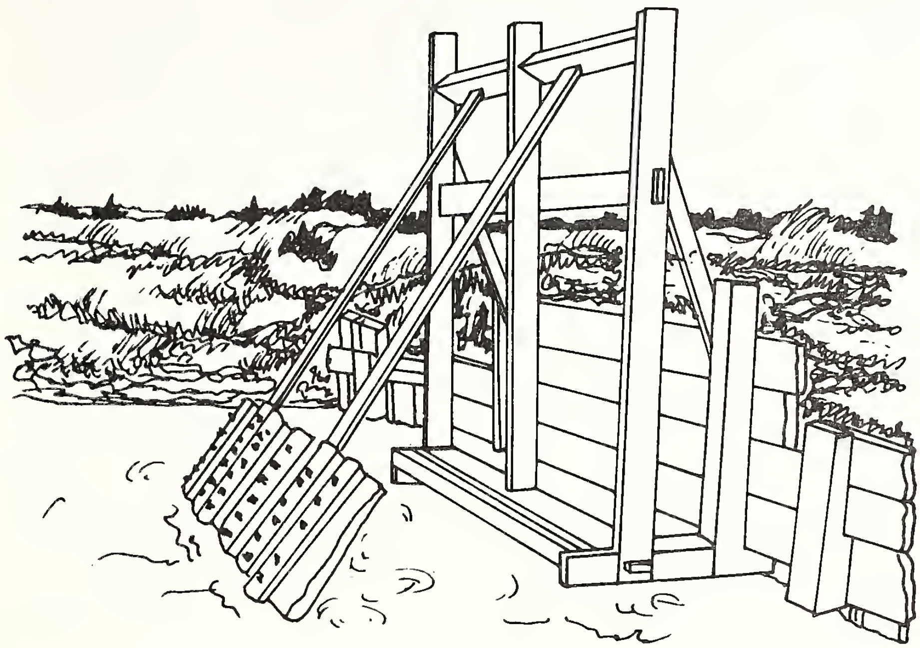


Figure 3-12. Flap gate for tidal creeks.

Source: Carlton and Jackson 1984

Slide gates may be installed in the same manner as flap gates. This structure is used principally in draining an area and often is used in conjunction with a flap gate on the outside end of the pipe. Again, this type of gate is not used if much runoff water is present, unless another structure is present to handle excess runoff.

Wooden Trunk. Although wooden trunks are more costly and bulky to install, they are preferred over metal covers because of their ability to handle greater volumes of water in a short period of time. Wooden trunks are resistant to salt water and can last at least 50 years with minimum maintenance.

Wooden trunks are of two basic designs: wooden flap gates at each end of the trunk and a box drop inlet for automatic field water level control. The former is probably more commonly used.

Wooden trunks are constructed of pressure-treated creosote timbers. Generally, all of the materials are precut before treatment to ensure that the ends of the individual pieces of timber also are protected by the treatment process. Individual pieces are assembled with wooden pins. Metal spikes and bolts often were used because of their ease in assembly. After a few years, however, the metal parts corrode and the trunk begins to leak because of loosened planks. Dimensions can be modified to meet individual installation, especially gate frames and gate members, which will depend upon the depth of water to be impounded and the height of the dike through which the trunk is placed.

If the drop inlet feature is not included in the trunk, then water level manipulation is provided through the adjustment of the two flap gates. If the water level on the field is to be built up through tidal activity, then the gate on the field side is lowered to cover the end of the trunk, and the gate on the outside of the field is raised to leave the trunk open. This will mean that on each tide, which may be higher than the water level in the field, the pressure will open the gate and cause water to flow into the field for as long as the high tide exists. The opposite is true if the field is to be drained. In this case, the gate on the field side is opened and the outside gate is closed.

Trunks of this type also can be used for taking in freshwater as the result of tide levels. If the dike is installed far enough upstream to be beyond the reach of the inflow of saltwater, then the inflow of this saltwater as a result of tidal action will increase the freshwater level in the stream and permit flooding of fields at high tide.

In some management operations, it is desirable to leave both gates open so that a flushing action occurs with the changes of the tide. This is especially true where accumulated organic sludge is to be moved from the channels within an old field.

Pumps for Subimpoundments

To flood or increase water depths in high-contour areas in the impoundment, the most practical approach is to subimpound by diking, and raise the water in these subimpoundments while maintaining desired water levels in the main pool. Part or all of the source water is diverted into the subimpoundment first and then it is spilled over into the main pool, or the water is lifted into these subimpoundments by means of pumping equipment.

Diversionary structures many times are initially more expensive on a large impoundment than are pumping installations, but over a period of years the maintenance and operating costs of pumping gradually will cause the pumping development to lose its economic advantage. However, because a gravity diversion system requires that water levels in the stream above the impoundment be raised to

gain the necessary advantage in head, this may be impractical if other interests along the floodplain of the stream will be adversely affected. Pumping is the only alternative if such impoundments are to be flooded (Linde 1969). In low impoundments, pumps may be used for drainage.

Selection of Pumps. The volume of water and range in lift governs the size of the power unit for the pump. Power is most economically obtained through the use of electric motors first, diesel engines second, bottled gas third, and gasoline engines fourth (Atlantic Waterfowl Council 1972). Pumps can be permanent or portable and mounted on a boat or pickup truck. Most are of three types: propeller, mixed flow, and centrifugal. Before obtaining and applying a pump, competent engineers should be consulted to help in planning the project.

(1) Propeller Pump. The propeller pump is especially adapted for low-head, high-volume operations. It has low operating costs and consists of a large pipe with an impeller at the intake end, a shaft running up the pipe to the power connection, and a discharge pipe running off at an angle. Volumes of 20,000 to 30,000 gallons per minute can be pumped. Numerous pumping plants of this type are found in both permanent and temporary installations where lift is less than 10 feet. In this type of pump, flow may be reversed if the pump is so designed. This is often a necessary requirement where water level control could be critical and there is a need for quick drainage as well as flooding.

(2) Mixed Flow Pump. This pump has an open-vaned, curved-blade impeller, combining screw and centrifugal principles in building up pressure heads. It operates more efficiently against higher heads than the propeller pump, handling as much as a 26-foot head.

(3) Centrifugal Pump. This is a high-head, high-pressure type used commonly where lifts exceed 12 feet. It delivers more water through smaller pipes than other designs, but operating costs are higher where large volumes of water must be moved. In many cases, volume of water controls the choice between this type and the other pumps.

Water Level Manipulation

Impoundment water levels are manipulated for several reasons:

(1) To establish desirable plants and discourage undesirable ones. Methods to accomplish this--depending on the species--include draining to kill undesirable plants, disking undesirable plants after draining, seeding after draining, and disking and seeding after draining.

(2) To create optimal ratios of open water to emergent vegetation. Ducks flourish with a ratio of 50:50.

(3) To encourage particular species of waterfowl and shorebirds by providing water depths appropriate to their needs.

(4) To expose mudflats, which encourages growth of certain plants and exposes lower vertebrates and invertebrates as food for various wildlife species. Exposed mudflats also tend to concentrate birds for viewing.

Partial drawdowns usually are better than complete drawdowns. Some water will be left for waterfowl broods. Invertebrates will not be reduced to levels so low that use by waterfowl broods will be affected the next year. Volunteer millet and smartweed will establish readily on higher ground because the groundwater table will not be reduced so drastically. Muskrats will survive better. Plant growth is less likely to fill in all open-water areas as it tends to with annual, complete drawdowns. Drawdowns every 2 to 4 years are generally best for waterfowl (Linde 1969). A scheme successfully used in Wisconsin is to draw down 2 or 3 years in a row, and then skip 1 or 2 years.

Timing Drawdowns

The timing of drawdowns varies with latitude and phenology of species migrating through or nesting. Because environmental conditions vary from year to year, water manipulations should coincide with the arrival and departure of wildlife species or with habitat conditions and not with a calendar date.

For waterfowl, drawdown should be as late as possible but early enough to allow seed production of fast-growing aquatics, such as wild millet, rice cutgrass, and annual smartweeds, which may become established on the moist mud flats. If tillage is needed, mudflats must dry. May 28 is generally used throughout the country as the best time to till, although in some States, tilling may occur earlier or later (Linde 1969).

For shorebirds, early spring drawdown to 0.4 to 6 inches is best to expose mudflats. In southeastern Missouri, for example, early to mid-April is best for lesser yellowlegs and pectoral sandpipers (Fredrickson and Taylor 1982). Gradually or daily fluctuating water levels, staggered by impoundments, will concentrate shorebirds on mudflats, which expose lower vetebrates and invertebrates as food. Observation towers, facing up the slope or gradient near the lowest point of the impoundment, provide excellent viewing for the entire drawdown period.

Late spring drawdowns should be done in two stages. First, water levels are lowered to 2 to 6 inches and held there until plants germinate on mudflats. Then drawdowns continue until completed. The first stage of drawdown should coincide with the arrival of herons, rails, or swallows. Depths required for various wildlife species vary.

Irrigation in Summer

During dry summers, plants should be irrigated by shallow flooding. The water is removed within 1 to 2 hours after the soil is saturated. When the plants are tall enough, the impoundment is flooded to depths of 2 to 6 inches (Fredrickson and Taylor 1982). Around the first of September, reflooding to about 12 inches occurs for early migrants such as blue-winged teal, sora, and gallinules. The water level gradually is raised to 18 inches. If the plants are very tall, the impoundment is flooded to a high level, perhaps 30 to 36 inches and gradually lowered to 18 inches as layers of seed are eaten. The first option is best for shorebirds, the second for waterfowl if plants are very tall.

Seasonal Manipulations to Attract Particular Groups of Wildlife

Fredrickson and Taylor (1982) listed marsh conditions suitable for both upland and wetland wildlife species. For example, a series of manipulations of waterfowl habitat (W) to increase attractiveness to shorebirds (S) would include a gradual dewatering to 2 inches in early spring; complete dewatering, disking to eliminate undesirable vegetation, and reflooding to 2 inches in summer; and increasing the water level (to the level of habitat W) in late fall and winter after shorebirds have migrated to their winter range. Various strategies (including no action) for various conditions exist. Figure 3-13 is an example of the kinds of records used for planning and for maintaining continuity in personnel changes.

AREAS WITHOUT WATER-LEVEL CONTROL

Level Ditches

Level ditches are constructed on level marshes to encourage muskrats and ducks. Suitable marshes generally are more than 2 acres in size. Soils suitable for ditching include peat, muck, clay, and silt. Sand, sandy loam, and clay high in salt content generally are not suitable (Yoakum et al. 1980). The following is a list of some important points to keep in mind regarding level ditches.

(1) Use a dragline for ditching.

(2) Contour ditches where slopes exceed 0.5 percent.

(3) On flat marshes exceeding 10 acres, locate ditches at 90° to prevailing winds and zigzag 10° to 30° about every 100 to 300 feet to impede wind and wave erosion.

(4) Space ditches 200 to 400 feet apart and dig 3 to 6 feet deep and 10 to 30 feet wide (Atlantic Waterfowl Council 1972).

Impoundment Number ____________________ Year ______________

Type of Manipulation: (1) Flood (2) Drawdown

Season of Manipulation: (1) Winter (4) Summer
(2) Early Spring (5) Early Fall
(3) Late Spring (6) Late Fall

Notes on Manipulation:

Date	Water level	Stoplog elevation	Notes

Animal Response:

Species	Arrival	Departure	Notes

Figure 3-13. Sample data sheet for moist soil manipulation.

Source: Fredrickson and Taylor 1982

(5) Slope sides at least 5:1 on one side in all soil types. Make the slope on the other side 3:1 in sand, 1:1 in peat, and 2:1 for all other soil types.

(6) Where controlled burning is unnecessary, make spoilbanks 3 feet from the ditch edge, no higher than 5 feet, flat on top, 40 feet long on alternate sides of the ditch, and with 10-foot gaps between the ends of the banks. Enlarge the ends of each spoilbank.

(7) In peat marshes subject to drying, place spoilbanks so that alternate areas between ditches can be control-burned without allowing peat fires and endangering the banks.

(8) Make spoil banks higher at the ends of each straight section of ditch to provide a windbreak.

(9) Seed spoilbanks to grasses and legumes to provide dense nesting cover.

Level ditches may be constructed in a circular, doughnut-shaped pattern to form a small island for waterfowl nesting and loafing. At a minimum, the island should be 20 feet across, although 50 feet is preferable for nesting and loafing areas for waterfowl.

Potholes

Potholes, which are shallow dugouts attractive to waterfowl, can be dug with a dragline or bulldozer, or they can be blasted with an explosive.

Digging Potholes

The most widely used method for constructing potholes is to excavate shallowly with a dragline. A bulldozer also can be used, except under very wet soil conditions. Although more expensive than blasting, mechanical construction is safer and more predictable. Mechanical digging is used more often than blasting (Holsapple and Lott 1979).

Blasting Potholes

Potholes are blasted by a licensed blaster as described by Mathiak (1965). A mixture of ammonium nitrate (standard fertilizer) and fuel oil (ANFO) is used (Figure 3-14). A 150-pound charge is best (Hopper 1978). Explosives can be valuable in marshy, vegetation-choked areas where use of heavy equipment is limited. However, explosives should not be used at sites with high organic soil content where they cause sloughing, or in heavy clay where they cause extremely steep sidewalls (Holsapple and Lott 1979). The minimum amount of ANFO used should be 50 pounds, which should blast a pit at least 18 feet wide.

Figure 3-14. Pothole construction by blasting.

Spacing Potholes

Potholes should be located to achieve an average density of 1 per acre. Cluster at least five at each location, all within 0.6 mile of larger bodies of water, as recommended by the Soil Conservation Service. A duck will use several potholes, so clustering encourages waterfowl concentration. For territorial nesters, potholes should be at least 150 to 200 feet apart.

Sizing Potholes

For courting, breeding, and brooding areas, potholes should be at least 2,000 square feet in size. When no brooding is anticipated, dugouts can be about 300 square feet. Dugouts in "L", "Y", oval, or circular shapes are preferable to square or rectangular shapes. For at least 25 percent of circular or oval dugouts, slope the sides 5:1 or flatter. End slopes of square and rectangular dugouts are best 5:1 or flatter. Side slopes in sand should be 3:1 or flatter, in peat 1:1 or flatter, and in other soils 2:1 or flatter. All spoil should be placed behind a berm at least 12 feet wide. Spoil should be leveled and seeded with grasses and legumes to develop dense nesting cover. In pastured areas, potholes should be fenced at least 25 feet, and preferably 40 feet or more, back from the water (Mathiak 1965).

Runoff Ponds

Runoff ponds are small impoundments (1 acre or more in size) located on upland sites. They are constructed by blocking natural drainage courses or large gullies with short dikes. If the surrounding area is maintained in grassy cover, emergency spillways should be incorporated for waterfowl brooding and nesting (Linde 1969). A drainage area of at least 20 acres is required for each 2.5 acres of water impounded, depending on local conditions.

Plugs

Plugs function as a form of small dike to prevent water levels in existing water areas from fluctuating or to increase the water area in a marsh (Atlantic Waterfowl Council 1972). Nonspilling earth plugs can repair damage to the marsh caused by mosquito or other marsh drainage projects. The plug of earth is fit into both sides of the drainage ditch, making sure that there is a good bond between the fill material and the bottom of the ditch.

Nonspilling wooden plugs may be substituted for earth plugs. Wakefield piling of creosoted lumber, long enough to prevent undercutting, is used. Wind walls should be long enough to prevent water from cutting around the end of the plug.

Spilling gut plugs of creosoted lumber are built to capture and retain high-tide flows. The high tide flows over the spilling gut plug to be retained in the ditch and surrounding marsh when the tide falls, thereby improving food conditions longer for waterfowl.

Pocosins

Pocosins are upland swamps on the Coastal Plain in the Southeastern United States. Habitat management is aimed at maintaining pocosins as open swamps because many have evolved into forest. Habitat improvement involves controlled burning, roll-chopping, and silvicultural practices (Personal communication, A. Boynton, North Carolina Wildlife Resource Communication). Roll-chopping is done with a bulldozer towing a heavy drum chopper to cut down vegetation and disturb the soil in summer, during dry periods, on areas not exceeding 50 acres. In succeeding years, vegetation is controlled by burning. Burns should be done in January and February and should not exceed 50 acres in size. There should be only a few inches of dry duff for fuel and the water table should be high enough to protect the peat. It is best to do burns just before a rain, which will extinguish the peat. Burns should be done every 4 to 6 years.

Because little pocosin habitat remains, sites should not be converted to loblolly pine. Existing pine plantations and other timber should be managed both for wildlife and for timber (see Integrated Management of Forests and Wildlife in Chapter 4).

NESTING HABITAT

Manmade Islands

Manmade islands serve several purposes. They decrease mammalian predation and human disturbance, they provide greater shoreline-to-surface ratio with larger capacity for territorial nesters such as Canada geese, and they provide secure brooding and loafing sites.

Earthen Islands

The following criteria should be considered when constructing earthen islands:

(1) For larger ponds, one earthen island 10 to 50 feet wide, with a freeboard of at least 3 feet and an area of at least 0.05 acre, is desirable.

(2) The island should be placed parallel to and at least 100 feet from the shoreline to avoid direct exposure to prevailing winds and wave action (Jones 1975).

(3) The side slopes should be 6:1 or flatter on 50 percent of the slopes, with the rest 3:1 or steeper.

(4) Native vegetation should be planted on the island. Topsoil can be added, if necessary, and the island should be seeded to grasses and legumes to develop dense nesting cover, which allows maintenance mowing.

(5) Islands can be built most easily during reservoir construction or drawdown. Peninsulas and tips of land can then be built up or separated from the mainland.

(6) Bulldozers and draglines should be used for earthmoving.

Floating Mats in Bogs

In bogs, floating mats can serve as islands but they should be anchored to prevent drifting to shore.

Brush Islands

Islands of brush are built in piles 10 to 15 feet across and high enough to be 4 feet above water. Limbs 6 to 10 inches in diameter are crisscrossed on the ice in winter, with small limbs on top and covered with hay or straw after they sink. Brush pile islands last 3 to 4 seasons (Linde 1969).

Hay Islands

Small islands of hay can be built and are attractive for duck nesting. However, they last only one season.

Floating Nest Islands

Floating nest islands (rafts) can be built of logs (Young 1971) or styrofoam (Fager and York 1975). The following steps describe how a styrofoam island is constructed:

(1) Styrofoam is cut (from shipping boxes for motorcycles, for example) and glued into a raft that is 4 feet by 4 feet or 4 feet by 8 feet that is 4 inches thick.

(2) A 2-foot-by-2-foot piece of styrofoam 2 inches thick is glued to the center.

(3) A shaped cover of chicken wire is placed over the styrofoam, with willow or bulrush laced in the mesh, and grass is placed in the enclosure (Figure 3-15).

(4) To make a rooting zone for plants, a channel is cut around the raft 3 inches deep, 8 inches wide, and 1 inch from outside edges.

(5) To allow water to seep in and keep root systems wet, 1/2-inch holes are drilled through the bottom of the channel.

(6) Soil and plants from the pond site are placed in the channels.

(7) To prevent coots from pecking holes in the styrofoam, the raft is framed with 8-inch wide bark-out pine.

Figure 3-15. Floating island of styrofoam for waterfowl nesting.

Source: Fager and York 1975

(8) The raft is anchored with one rope and a 25- to 30-pound rock. A 2-foot square stablizer is spliced into the rope 3 feet from the raft to keep it from whipping around in the wind.

Nesting islands also can serve as loafing areas for waterfowl. Small loafing places can be made by anchoring logs or 4-foot-by-4-foot rafts in open water, or by stacking rocks, old straw, or hay bales in shallow areas (Atlantic Waterfowl Council 1972). The Soil Conservation Service recommends three sites per acre. Muskrat houses are also useful for loafing.

Nest Boxes

The territorial requirements of individual species dictate the spacing of nest structures. Near water areas, nest structures often are effective for increasing wood duck populations. Unlike most other ducks, wood ducks will tolerate close nesting, so boxes placed in clusters are used more often (Bellrose 1980), in a density of two to four boxes per acre, with a proper predator guard. For best use, wood duck nest boxes are placed over water. They also can be placed a maximum of 1 mile from water, although a location of one-fourth mile is better. Boxes should be located 12 to 20 feet above ground at 90° to prevailing winds, with the entrance toward water. Two basic types of wood duck nest boxes in widespread use are wood (shown in Figure 3-16) and metal (shown in Figure 3-17).

These boxes also are used by buffleheads and hooded mergansers, as well as kestrels and various songbirds. If starlings are a problem, a horizontal nest box is a better solution (McGilvrey and Uhler 1971). Nest boxes for insectivorous birds are described in Integrated Management of Forests and Wildlife in Chapter 4.

Platforms and Baskets

Species of waterfowl known to use nest baskets and platforms are the Canada goose, mallard, blue-winged teal, gadwall, pintail, redhead, and canvasback. The structures for geese (Figures 3-18 through 3-20) should be spaced 50 to 75 feet apart. For ducks (Figure 3-21), the structures are clustered in diamond-shapes of four, with one cluster per 1 mile of shoreline, located 30 to 300 feet from shore in sheltered areas near emergent vegetation (Doty et al. 1975, Yoakum et al. 1980). (See Figure 3-22.)

Treated poles--6 to 8 inches in diameter--are placed in the rookery with platforms for double-crested cormorants, great blue herons, and black-crowned night herons within 25 feet of natural nesting trees (see Figure 3-22). This is best done in winter through the ice. Modified lath platforms (Figure 3-23) are attached to the poles 9 to 24 feet above water, 3 feet apart, vertically for cormorants and 4 feet for herons, staggered in a 180° rotation pattern (Meier 1981).

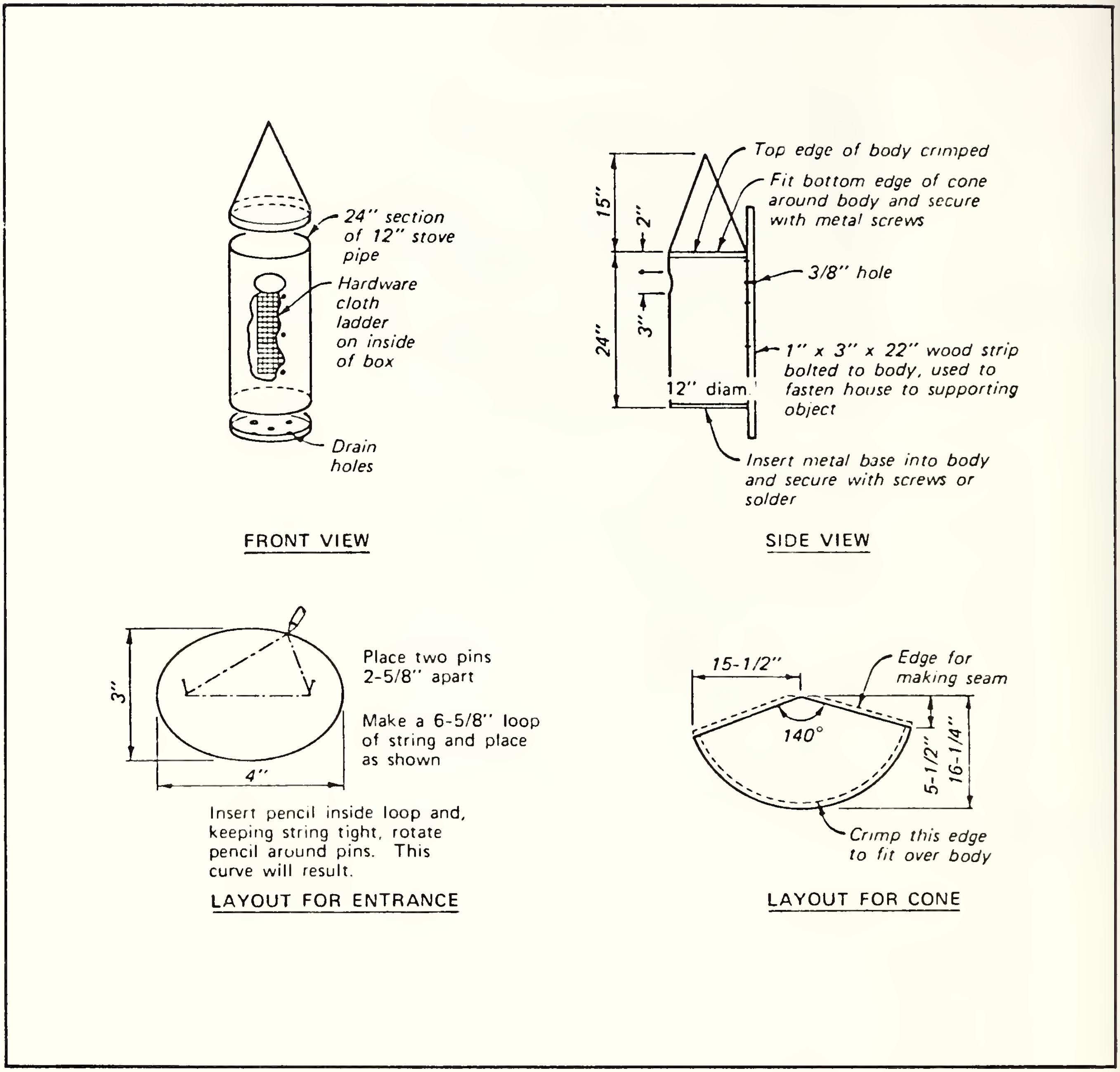


Figure 3-16. Constructing front-opening wooden nest box for wood ducks.

Source: Martin in press, adapted from Bellrose 1980.

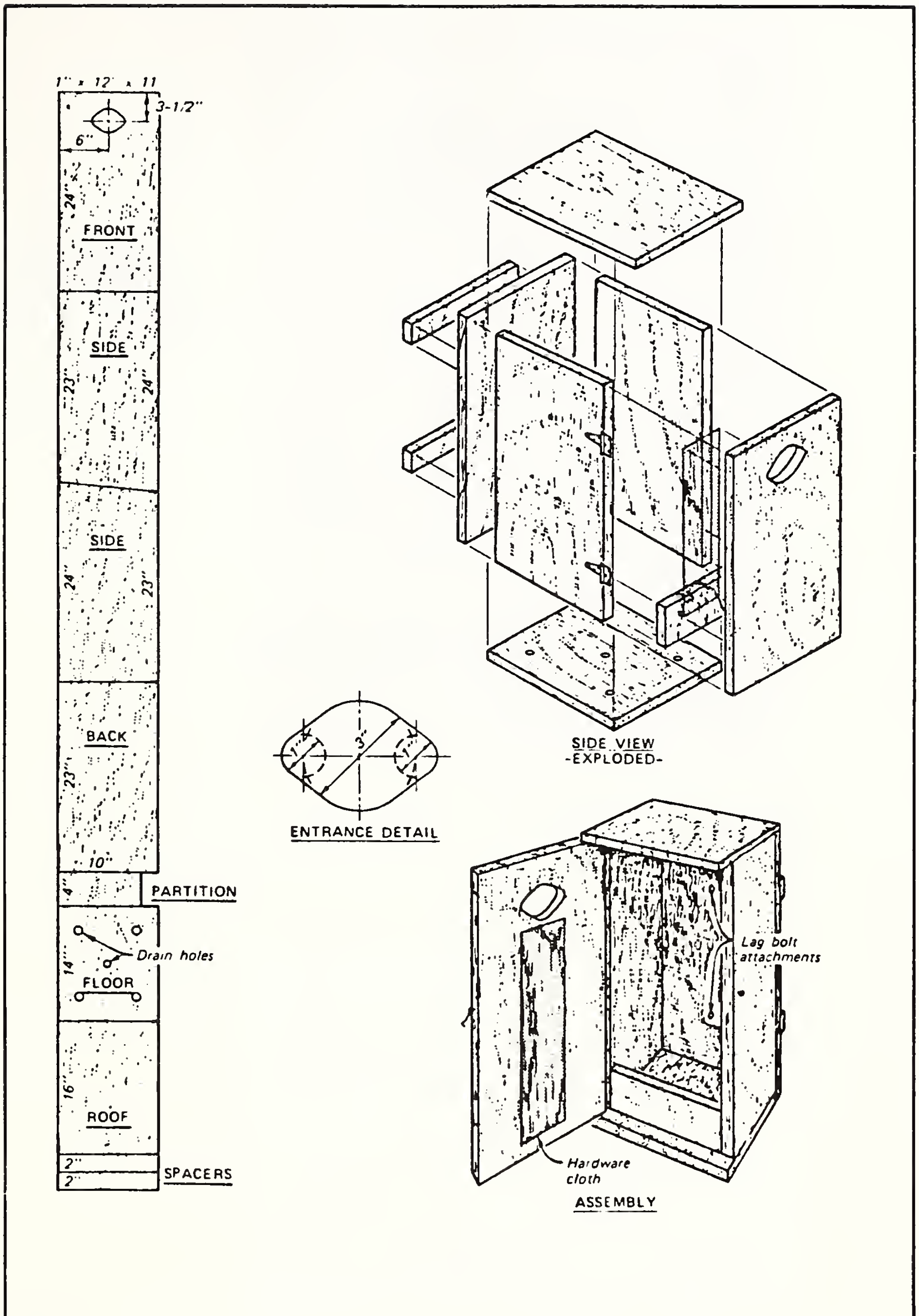


Figure 3-17. Vertical metal nest box.

Source: Martin in press, adapted from Bellrose 1980

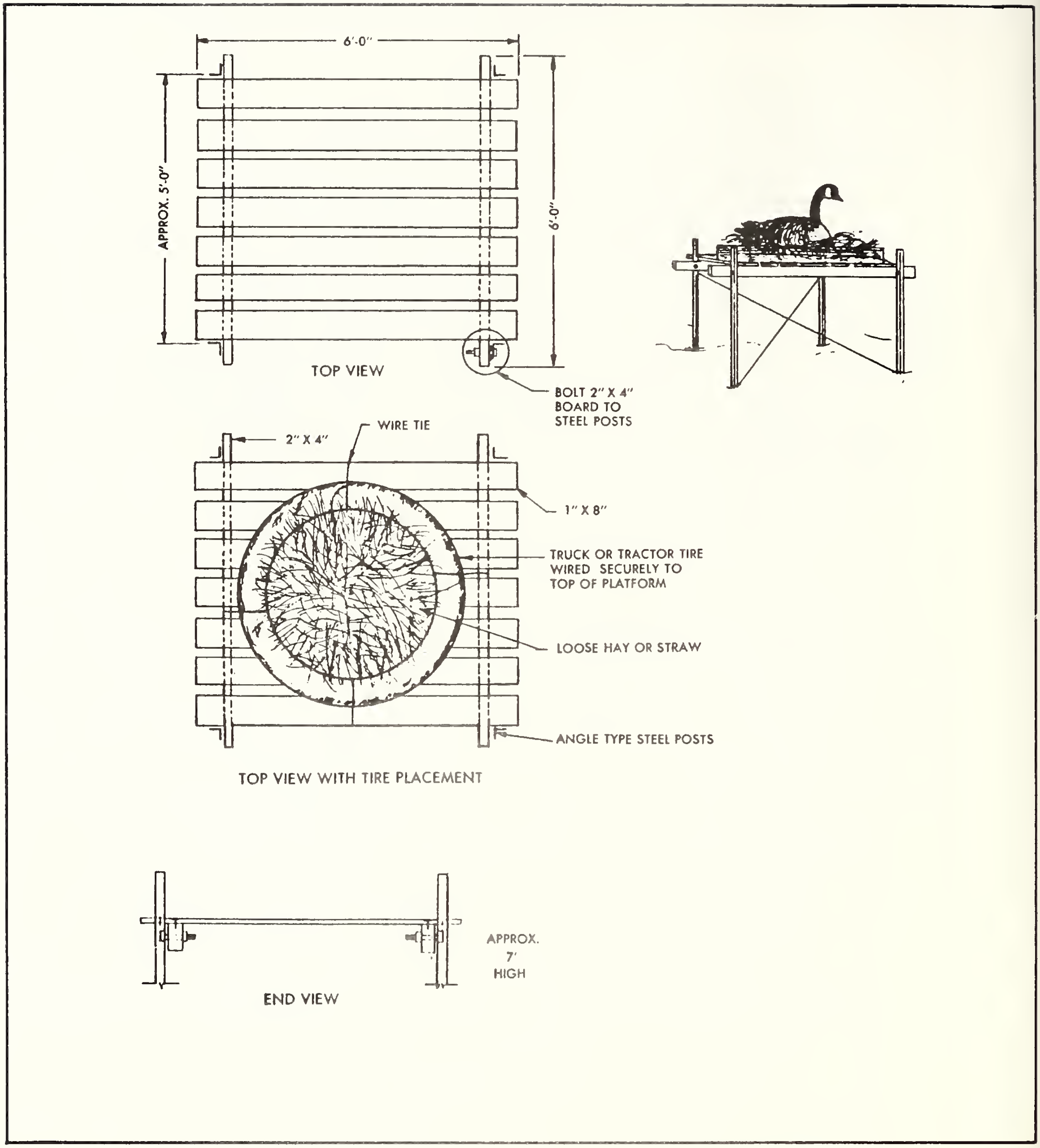


Figure 3-18. Plans for constructing a goose nesting platform.

Source: Yoakum et al. 1980

Figure 3-19. Snow fence structures for geese.

Source: Grieb and Crawford 1967

Figure 3-20. Floating nest structure in use.

Source: Grieb and Crawford 1967

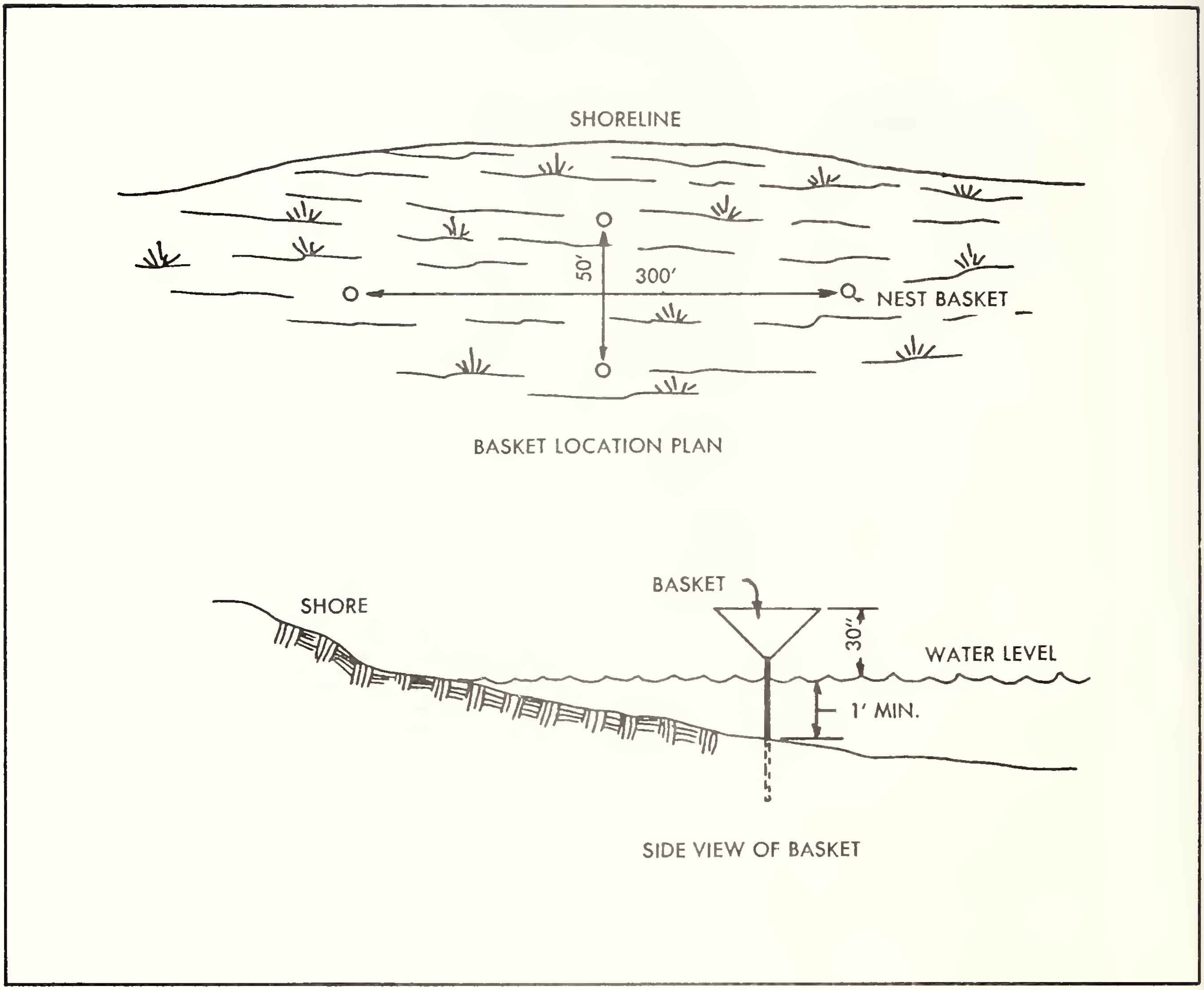


Figure 3-21. Cluster placement of waterfowl nest baskets.

Source: Yoakum et al. 1980

The first step is to ensure that firm soil exists on the flowage or lake floor for pole placement.

A hydraulic soil auger is then placed through the hole in the ice, and drilling extends to a depth of 6 feet for a 30-foot pole.

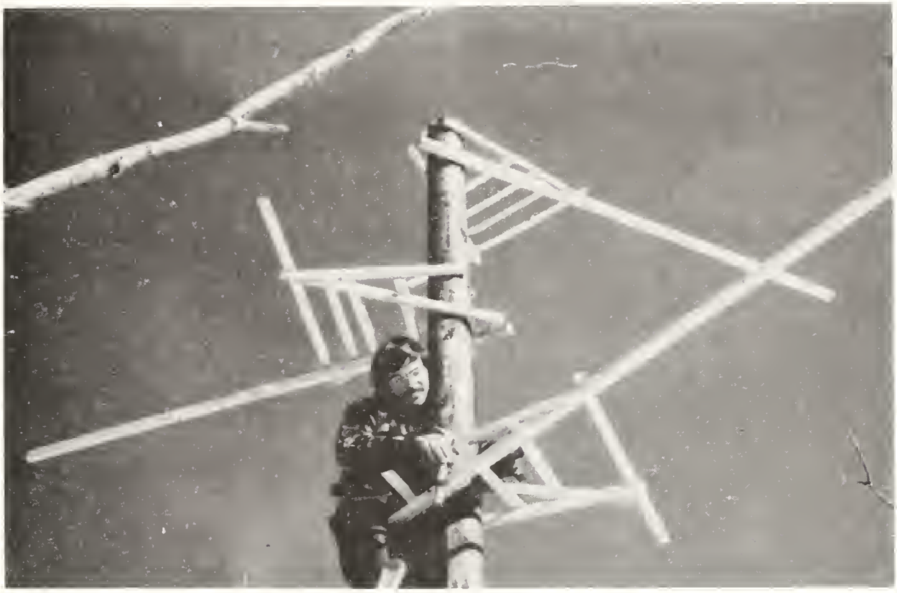
Figure 3-22. Procedures for installing artificial nesting platforms for double-crested cormorants, great blue herons, and black-crowned night herons.

Source: Meier 1981

The pointed butt of the pole is placed over the hole and the bulldozer is backed up slowly, raising the pole until the pole is vertical and slips into the drilled hole.

Figure 3-22 (continued). Procedures for installing artificial nesting platforms for double-crested cormorants, great blue herons, and black-crowned night herons.

Source: Meier 1982

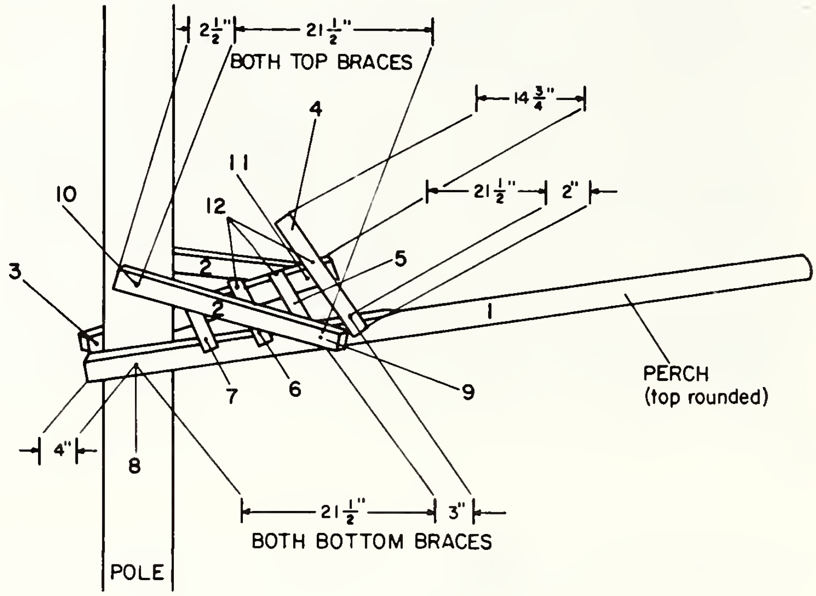


Partially assembled platforms are bolted on the pole, and construction is completed in place.

Platforms placed consecutively in 180° rotation are recommended. Platforms such as these have a projected life expectancy, if new, of 45 years, and if used, 15 to 20 years.

Figure 3-22 (continued). Procedures for installing artificial nesting platforms for double-crested cormorants, great blue herons, and black-crowned night herons.

Source: Meier 1982



MATERIALS

(1)	2" x 2" x 7'	(7)	3/8" x 2" x 17 7/8" lath
(2)	1" x 2" x 26½"	(8)	3/8" x 3½" lag bolt and washer
(3)	1" x 2" x 30"	(9)	5/16" x 3" machine bolt and washer
(4)	3/8" x 2" x 39" lath	(10)	3/8" x 2½" lag bolt and washer
(5)	3/8" x 2" x 19½" lath	(11)	5/16" x 2½" machine bolt and washer
(6)	3/8" x 2" x 19¼" lath	(12)	1¼" ring shank nails

Figure 3-23. Materials and measurements for constructing a modified lath platform.

Source: Meier 1982

Nesting platforms for ospreys are spaced at least 300 yards apart. The Sanibel Tripod (Figure 3-24) is lightweight and portable for use in remote areas, with removable steps (Figure 3-25) for monitoring (Webb and Lloyd in press). Where weight is unimportant, more permanent structures should be installed.

Nesting Meadows

Nesting meadows generally extend at least 300 feet from the water's edge (Atlantic Waterfowl Council 1972). Development includes clearing shrubs, trees, and stones; site preparation; and seeding to an adapted grass/legume mixture. Bunch grasses work best. Vegetation should be at least 12 inches high, although 18 inches is preferable. Reinvasion of woody species requires mowing on a rotation schedule. Maintenance of meadows may include top dressing with fertilizer.

UPLAND FOOD PRODUCTION FOR GEESE

Because geese are grazers, they benefit from upland farming within 1 mile of wetlands frequented by geese. Crops produced for geese--corn, sorghum, ryegrass, winter wheat, arrowleaf clover, and crimson clover--also provide forage for other wildlife (Givens et al. 1964). Sharecropping reduces time, labor, and farm machinery expenses. For instance, the farmer contracts for all the hay he plants and half the corn and cannot mow until after July 1. The farmer benefits by receiving a crop on land that he does not own and that is not taxed. Crops should be planted in strips of varying length and width to maximize edge effect. Standard farming procedures are used for site preparation, fertilization, seeding, cultivation, and irrigation. The planting and maintenance of dense nesting cover for ducks should be worked into the farming strategy.

VEGETATION CONTROL

The major objective of controlling vegetation is to replace undesirable plants with plants that serve as wildlife food and cover. A secondary objective is to develop a 50:50 ratio of emergent plant cover to open water to benefit waterfowl populations.

Drawdowns

Water manipulation by itself or used in conjunction with other methods often produces satisfactory plant control. As described in the section Water Level Manipulation, drawdowns during spring expose mudflats and kill undesirable emergent plants. The mudflats are then seeded naturally or artificially with desirable moist soil plants, and the water is replaced in late summer.

Overwinter drawdown exposes plants to freezing and dessication and thus is very effective. A partial drawdown also may work; when the plants freeze in the ice, water is added under the ice to float it, thus tearing out the plants (Nichols 1974).

A complete drawdown for 2 years will kill cattails by dessication (Nelson and Dietz 1966). Deep flooding to 3 feet for 2 years

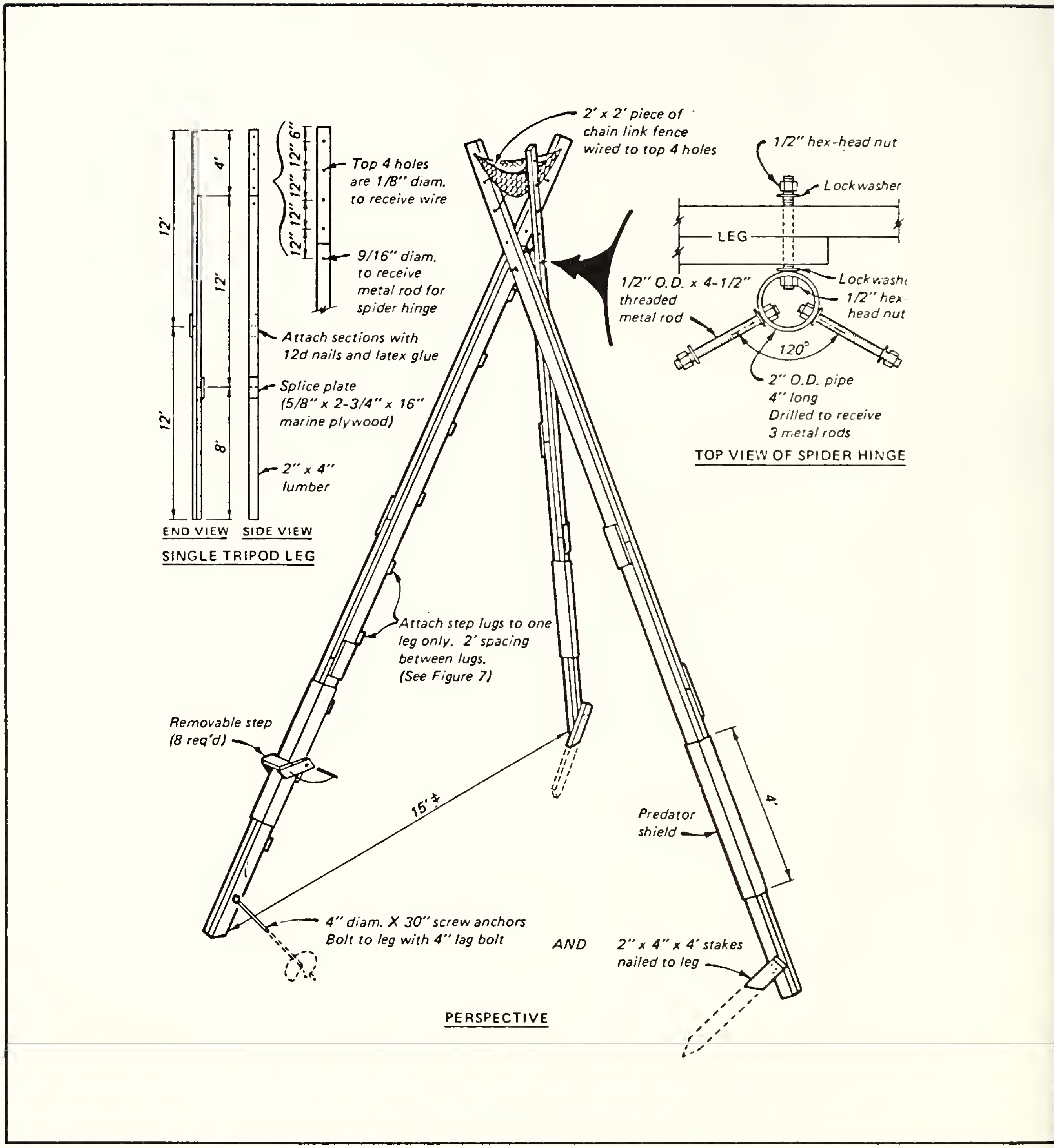
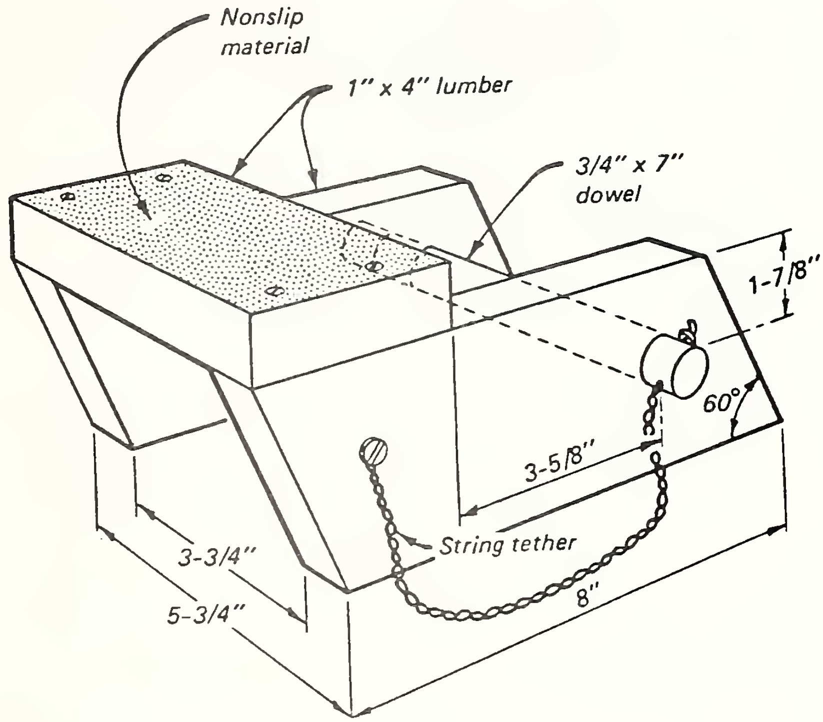


Figure 3-24. Design specifications for a Sanibel tripod nesting platform for ospreys.

Source: Webb and Lloyd in press

PERSPECTIVE VIEW OF STEP



NOTES

Materials are 1 x 4" stock.

Parts are glued and fastened with wood screws.

String tether keeps dowel with step.

Step lugs are attached to one leg of tripod to keep steps in place.

Top step is 9" wide to support both feet of investigator.

Nonslip material should be glued to steps.

Figure 3-25. Construction details and materials for removable steps for the Sanibel tripod.

Source: Webb and Lloyd in press

kills about half the cattails, and virtually all are killed in 3 years (Beule 1979). High water for 3 to 4 years also kills purple loosestrife (Mattfield 1984).

Mechanical Methods

Mature cattails are controlled by cutting in late July or August, using a standard tractor or crawler tractor with 2-inch by 4-inch or larger oak cleats bolted to the tracks, 3 inches or more below water surfaces or flooding the cut stems with that much water (Beule 1979). A second cutting of resprouts is especially effective (Nelson and Dietz 1966). Cutting at ice level in winter, so spring run-off covers the cut stems, also controls cattails. The cookie cutter is a self-propelled machine that can gain access to remote areas inaccessible to draglines. It can open up areas choked with cattails and other plants by cutting through a layer of soil as it works its way through 18 inches or more of water.

Scraping a dried out marsh in winter with a dozer or dragline can also control cattails. However, crushing with a standard roll crusher pulled by a dozer with wooden cleats or disking are ineffective for cattail control because results are temporary (Beule 1979). Furthermore, flooding in spring causes disked cattail tops to float, completely covering water surfaces. An effective strategy to control cattail and purple loosestrife used in New York was to drain in May or early June, use a Rome disk with a D-8 dozer in August, and reflood in fall (Mattfield 1984).

Prescribed Burning

Prescribed burning generally is ineffective for cattail control, except when it burns into the peat. Awaiting proper burn conditions and complying with air pollution restrictions limit the usefulness of burning in plant control (Beule 1979). Root burns may be desirable to remove climax vegatation and set back plant succession, which usually produces food plants more attractive to ducks (Yancy 1964). Root burns, however, alter the marsh structure more than cover burns, so it generally is not a good practice to burn during abnormally dry spells (Rutherford and Snyder 1983, Yancy 1964).

Peat burns are used mainly in long-established freshwater marshes to develop ponds from 0.5 to 2 acres in size, but they are used only if the remaining peat fires can be extinguished by immediate flooding. Peat burns are used on extremely dry marshes with a layer of dry peat. Heavy growths of vegetation are burned every 1 to 3 years during periods of low humidity where wind speed is less than 6 miles per hour. In arid regions, burning should take place in late afternoon or evening, or when the ground is frozen and perhaps has a light snow cover. The size of the burn is controlled by the presence of roads, waterways, or other barriers. Typically, the downwind portion is ignited first (Yancy 1984) and burning occurs in small plots (Rutherford and Snyder 1983). The Prescribed Burning section in Chapter 4 provides additional information.

Physical and Chemical Methods

Methods such as fertilizing and liming, turbidity, shading with plastic sheeting, and blanketing with a layer of sand or gravel are described in Chapter 20. In general, cattails can be controlled by spraying 5 to 9 pounds per acre of a concentrated water mixture of Amitrol T, Radapon, and Dowpon in mid-July or later with a gun-type high-pressure sprayer mounted in an all-terrain vehicle. This type of sprayer can cover a width of 10 to 13 feet. A helicopter rigged for spraying also can be used, which controls cattails when flooding occurs the following year (Beule 1979).

Wave action may prohibit growth of aquatic vegetation in some ponds. The common threesquare bullrush and the hard-stemmed bullrushes are most suited to withstand wave action (Addy and MacNamara 1948). After these plants become established, wave action may be retarded enough to allow more desirable plants to become established. To break the force of waves and permit growth of plants in shallow water near shore, a continuous series of floating log booms is attached in units of two or three logs, with about 2 feet between logs. These booms are anchored in a line offshore (Addy and MacNamara 1948). To reduce wave action on large ponds, strategically placed islands are dredged and protected by vegetation or riprapping.

Biological Methods

Muskrat Management

Management of cattails ideally should involve a management program for muskrats. Marsh management for muskrats requires a constant water level of about 18 to 24 inches and cattails. Muskrats use cattails for food and to build houses. A high muskrat density will check the spread of cattails and will help maintain the 1:1 ratio of open water to emergent plant cover that is desirable for ducks. If cattails and bullrushes for muskrats are not abundant, pieces of root with attached buds can be transplanted into the muck at impoundment edges (Rutherford and Snyder 1983). Cattle should be fenced out to encourage muskrats.

However, too high a muskrat density results in expensive maintenance of dikes because muskrat burrows cause severe dike erosion. Trapping programs and periodic drawdowns can be used to keep muskrat population in balance with cattail control and dike damage. To encourage muskrats in areas with dense stands of cattails, an area 15 feet in diameter should be cleared with a scythe or herbicide. Three bales of hay or straw are placed in the opening in the water, 2 to 3 feet deep, one bale on top of two (Hamor et al. 1968). Muskrats will create more open water as they use the bales as houses or loafing sites.

Controlled Grazing

Rest rotation grazing can be used effectively and economically to control vegetation on wetlands, especially where moisture patterns

and growing seasons encourage fall regrowth of vegetation (Eng et al. 1979, Rees 1982). The pasture most attractive to breeding waterfowl pairs in spring is the previous year's rest pasture. Pastures grazed only during spring and early summer are somewhat less attractive (Table 3-1).

Sheep can be controlled more easily than cattle, can be maintained in a close band by a herder, and can eliminate undesirable plants more readily by grazing closer. Sheep can be forced into dense stands of vegetation to open potholes. Controlled sheep grazing also firms the dikes, fills in expansion cracks, seals muskrat dens, adds fertilizer, and reduces predator cover (Ermacoff 1968). However, care must be taken to prevent the sheep from excessively trampling bare shoreline.

In the Southeast, the Soil Conservation Service recommends controlled grazing of areas 50 acres or larger, especially where alligatorweed is dominant. The area should be drained, making sure it is dry enough to support cattle, burned in late February or March, and then grazed to reduce undesirable plants and encourage smartweed. Cattle should be removed in October or before they nip the smartweed--an unpalatable species for cattle. The area should be reflooded 6 to 12 inches deep.

In the northern Midwest, the following summer stocking rates leave ample nesting cover for ducks: one cow for every 2 to 4 acres of grass in Iowa, Wisconsin, and Minnesota; one cow per 8 to 12 acres in the eastern Dakotas; and one cow per 12 to 15 acres in the western Dakotas and central Nebraska (Bossenmaier 1964). Denser stocking rates should be used to control tall, rank, wet-meadow vegetation. Grazing generally begins when new growth is 3 to 6 inches tall--about May in northern States. The coarse species of lowland plants are grazed earlier because they make up most of the undesirable vegetation in waterfowl breeding areas and are most palatable early in spring. Areas should be separated by fencing or by strategic placement of salt licks.

Riparian habitat will be altered when more than 60 percent of the riparian herbage is used by cattle, and in some cases when more than 25 percent is used (Platts 1982). Sheep grazing in a 3-pasture rest-rotation system has little impact on riparian habitat (Platts 1982). Streamside zones should be considered as key management areas in grazing systems. Mineral supplement like salt licks, used with or without water development, can draw livestock to upland sites. Stock driveways and trailing areas should be located away from streamside zones. Small groups should be moved in slow drives through riparian areas to minimize impact. Stock bridges or revetments should be constructed at crossings if necessary.

Table 3-1. Grazing rotation schedule.

Pasture	Spring	Summer	Fall	Spring	Summer	Fall	All Seasons
		Year 1			Year 2		Year 3,4,5--
1 (small)	Graze	Defer	Graze	Defer	Graze	Defer	Rest
2 (large)	Defer	Graze	Defer	Graze	Defer	Graze	Rest
3 (small)	Graze	Defer	Graze	Defer	Graze	Defer	Rest

Source: Rees 1982

Because riparian habitat is probably the single most important, least abundant, and most abused plant community for wildlife (Rutherford and Snyder 1983), most should be fenced and protected.

Food Plants

Plants should be propagated for waterfowl food only after a thorough survey of existing conditions. First, the minimum requirements for all important duck food plants present or missing from the area should be identified and inventoried. Planting, the last step in the program, takes place only when it has been established that important species are missing and that conditions for their introduction are suitable. Generally, fluctuating waters should be managed for annual food plants (like millets) and woody emergent cover (like willows and buttonbush). Stable impoundments should be managed for emergents (like bullrush) and submerged aquatics.

There are many factors to consider in propagating, transplanting, and maintaining food plants for waterfowl.

(1) Invertebrates. Marsh food plants serve waterfowl directly as food and cover, as well as indirectly as food and cover for invertebrates so important to broods and laying hens. If the pH of the marsh is too acidic to support invertebrates, liming may be desirable.

(2) Timing Drawdowns and Planting. Drawdowns to expose mudflats must occur early enough to allow food plants to mature but late enough to avoid spring frosts. In northern States, for example, seeding dates for Japanese millet, which matures in about 70 days, occur about May 15 to June 30 (Linde 1969).

In many situations, food plants such as sticktight (Bidens spp.) and smartweed will volunteer, but in others, they must be seeded. Seeding can be done at three different times to extend seed availability when mature. In northern States, reflooding to 2 to 6 inches begins August 1, although September 1 is the more commonly used date. Early flooding prevents early frost damage. Thereafter, progressive flooding in 6- to 18-inch stages allows ducks to glean different levels of seed. Drawdowns should not occur every year in the same flowage because undesirable emergent vegetation will become established. Drawdowns should be rotated by flowage.

(3) Planting Japanese Millet. The seeding rates of Japanese millet are 20 to 30 pounds per acre. Mudflats are seeded by hand, either broadcasting the seed or with a hand-operated cyclone seeder aboard a small crawler tractor. Cleats 2 inches by 4 inches and 30 inches long are bolted to the tracks for better traction. For mudflats larger than 25 acres, aerial seeding is best. A commercial cropdusting plane is used at an altitude of 35 feet. If tillage is needed, various types of breaker plows, discs, or rotovators can be used.

(4) Harvesting and Transplanting. Except in a few cases, seed is harvested during the period between ripening and shattering (Stanton 1957). Tubers and rootstock usually are harvested in early spring. Tubers and other propagating materials that develop under water should be kept wet during transport and storage. Planting can take place in fall or spring--each option has advantages and disadvantages. Many seeds need an over-winter dormant period at temperatures just above freezing. Entire plants or vegetative parts of aquatics usually can be transplanted any time. Erickson (1964) described circumstances and procedures for transplanting marsh plants.

(5) Using Less-Desirable Species. Where improvements are not feasible, some normally less-desirable plants may be tolerated. For example, watershield and naiads serve as good food plants and are fairly easy to establish in acid-stained water (Burger 1973). Also, needlerush, spatterdock, cattail, and other emergents, while normally undesirable, may create the only emergent cover on lower quality areas or protect shorelines or newly developed marshes until more desirable plants can be established.

(6) Submerged and Floating Plants. Submerged plants are primary food for diving ducks but important to dabblers as well. Pondweeds are among the best, with sago pondweed preferred. Submergents are transplanted by pulling or digging in spring, balling the roots in mud to keep them moist, and embedding or

dropping them into the new site in small clusters weighted in clay balls or with a small sinker (not lead). The bottom should be soft and muddy and the same depth as the original site (Burger 1973). Submergent species, such as pondweeds, wildcelery, naiads, and widgeon grass, are most productive in clear water less than 6 feet deep. Where the bottom is suitable in water 2 to 6 feet deep, a handful of seed, such as sago pondweed, should be broadcast about every third step to seed 1 acre with about 1 bushel of seed (Erickson 1964). Duckweed should be transplanted in a bucket of water (Burger 1973).

(7) Emergent Plants. As a general rule, cattails, bullrushes, sedges, wildrice, and other plants that rise well above the surface should not be planted in water deeper than 2 feet (Erickson 1964). Alkalai bullrush is an important emergent in salt wetlands of the Southwest, but it requires special management to establish a seeding bed. Wildrice is one of the best emergents, but it is hard to establish. It needs fresh--not stagnant--shallow water in a sunny area with a soft mud bottom. The seed is broadcast onto the water where it sinks to the bottom for germination.

(8) Shoreline Plants. Shoreline vegetation should be transplanted for food and cover or erosion control. This should be done in clumps for small areas or seeded. Wild millet, smartweed, sedges, rice cutgrass, and some panic grasses are among the best shoreline plants (Burger 1973).

Dike soils should be stabilized with vegetation having a good root structure. Reed canary grass is often used for this purpose, although it develops into dense nesting cover that attracts waterfowl. This exposes them to high mortality from predators that use the narrow dikes as travel lanes. Mowing should occur in late fall or early spring to reduce attractiveness for nesting. Standard procedures are used for site preparation, fertilization, and seeding to establish vegetation on dikes.

To develop riparian habitat quickly in arid regions or to protect streambanks, transplant rooted cottonwood cuttings. To root cuttings, cut down native cottonwoods (for example, narrowleaf cottonwood, plains cottonwood, and coyote cottonwood) 4 to 8 inches diameter-at-breast-height and cut into 6- to 8-foot lengths, or cut samplings 6 to 8 feet long, or saplings during winter dormancy, 3 to 6 feet high, trim branches, and place into a barrel of water with a rooting hormone. Each tree should be notched with true north for proper orientation when transplanted. Holes 3 to 4 feet deep should be drilled close to the water so that the trees can be set directly in the water table. The bark of the portion below ground is scratched through to allow water to penetrate

readily. Soil is tamped firmly around the base and tar painted on exposed cut areas to retard disease and insect infestation. Sprouting should occur in 2 to 4 weeks, with new trees becoming 6 to 9 feet tall the next summer (Miller and Pope 1984).

(9) Native Plants. More than two dozen species of plants appeared as volunteer growth around blasted potholes on the Chippewa National Forest in Minnesota 3 years after the holes were created. Half of the common species were valuable as duck food; others were desirable for cover. The entire association provided good waterfowl habitat. On the other hand, trails with two species of nonnative millets were unsuccessful around beaver ponds on the Monongahela National Forest in West Virginia because the strains used were not adapted to the frost seasons. This illustrates the importance of encouraging the spread of desirable native plants. A list of native plants found in and around some potholes in Minnesota, with their importance as duck food, is shown in Table 3-2.

ICE CONTROL

Some warm water sloughs in some parts of the United States have enough volume of water to remain ice-free during winter. Such areas accommodate wintering ducks. Watercress and other aquatic vegetation may choke such areas and inhibit water flow, causing the water to cool too fast and freeze. Excess vegetation should be removed by hand or power equipment (Rutherford and Snyder 1983). Some areas can be kept ice-free by shallow-well pumping. Ice-free areas also can be provided by aerating ponds with compressed air systems, but the expense for such methods rarely can be justified.

Table 3-2. Volunteer vegetation around a Minnesota pothole.

Scientific name	Common name	Occurrence	Duck food value
	Emergent Vegetation		
Equisetum palustre	Horsetail	Occasional	None
Typha latifolia	Common Cattail	Common	None
Sparangium chlorocarpum	Burreed	Fairly Common	Fair
Glyceria borealis	Mannagrass	Common	Fair
Calamogrostis canadensis	Bluejoint Grass	Abundant	None
Agrostis scabra	Hairgrass Bentgrass	Occasional	None
Scirpus pedicellatus	Bullrush, Three Square	Fairly Common	Very Good
Carex spp.	Sedge	Common	Slight to fair
Juncus spp.	Rush	Common	None
Polygonum convolvulus	Bindweed	Occasional	Good to Excellent
Ponentilla palustris	Marsh cinquefoil	Occasional	None
Cicuta bulbifera	Water hemlock	Occasional	None
Sium suave	Water parsnip	Fairly Common	None
Lycopus uniflorus	Water horehound, bugleweed	Occasional	None
Mentha arvensis	Mint	Occasional	None
Galium trifidum	Bedstraw	Occasional	None

Table 3-2 (continued). Volunteer vegetation around a Minnesota pothole.

Scientific name	Common name	Occurrence	Duck food value
	Submerged and Floating Vegetation		
Potamogeton foliosus	Pondweed	Commmon	Fair to good
P. epihydrus	Pondweed	Fairly Common	Fair
P. natans	Pondweed	Occasional	Fair to Good
Lemna minor	Duckweed	Common	Good to Very Good
Utricularia vulgaris	Bladderwort	Common	None
U. intermedia	Bladderwort	Occasional	Little or None

Chapter 4
Upland Habitat Improvement

INTRODUCTION

Upland habitat improvements focus on supplying any of the three essential elements of wildlife habitat--food, water, and cover--that are lacking. Interplay among the elements is significant: techniques to manipulate vegetation to improve food supply will result in changes to cover; habitat manipulation to encourage some species will always discourage others, because species occupy specific stages of succession. Before undertaking improvements, the total effect on the ecosystem should be determined to assess the desirability of the consequences.

VEGETATION CONTROL

Vegetation can be released through thinning or reducing other competition; rejuvenated through pruning by killing or removing old, tough, or dead material, crushing the plant to invigorate it, or fertilizing or irrigating the vegetation to accelerate growth; and planted through seed and transplants. Projects should be planned with regard to temperature, precipitation, humidity, geological formation, soil, slope, aspect, plant ecology, and biological agents. The USDA Forest Service (1969a, 1973a) has described range revegetation and type conversion.

The size and pattern of treatments should be geared to the requirements of the wildlife species involved, relative to home range and movement patterns. The amount of forage produced should be geared to the number of animals that will use it. Presumably, improvements in food and cover will increase the wildlife density, unless social intolerance interferes. If use is too light, additional forage may grow out of reach rapidly or become as dense as the original untreated stand. If treated areas are small enough for moderately heavy browsing to hold plants within reach, value will be prolonged.

Release From Competition

There are four general methods of releasing plants that are desirable for wildlife from competition with less desirable plants: mechanical, chemical, prescribed fire, and biological. Pechanec et al. (1965) compared three of these methods in treating big sagebrush (Table 4-1). Often the methods are used in combination to meet specific needs (Green 1977).

Treatment should be in strips, wherever practical, to create edge habitat. Increasing the amount of edge will maximize wildlife use and species diversity (Robinson and Bolen 1984). For example, Castrale (1982) found that alternating 330-foot-wide strips of treated sagebrush with 330- to 660-foot-wide strips of untreated sagebrush maximized the diversity of bird species.

Table 4-1. Summary of limitations and advantages of the six most common methods of big sagebrush control.

Item	Method of Control: Prescribed Fire	Spraying With Herbicides	Plowing or Disking Once Over
Kill of big sagebrush.	95-100 percent of all ages.	50-99 percent of large old; slightly less of young.	70-99 percent of old; slightly less of young.
Kill of associated undesirable plants.	Not effective on sprouting shrubs and some annuals.	Good on rabbitbrush resprouted after fire.	Usually not effective on sprouting shrubs; good on cheatgrass.
Effect on desirable forage plants.	Low kill of grass, 30-40 percent loss in vigor first year. Non-sprouting shrubs killed.	Grass not damaged; some broad-leaved herbs and nonsprouting shrubs may be damaged.	Kills all except those that sprout or spread by rootstocks.
Ease of seeding after treatment.	Easily done with drills; seed can be aerially broadcast and covered with anchor chain or pipe harrow; firm seedbed.	Standing dead brush may be barrier to drilling. Seed can be aerially broadcast and covered with anchor chain or pipe harrow.	Easily done with drills; seedbed may require packing.
Adaptability to terrain and soil.	No limit except as imposed by fire danger and erosion hazard.	Virtually unlimited.	Limited to little or no rock except with brushland plow.
Availability of equipment.	Equipment generally available; brush rake useful; experience primary need.	Commercially available.	Plows and disks commercially available; brushland plow is custom made.
Effect on erosion hazard.	Exposes soil, destroys litter (unsuited to highly erosive areas).	Slight if any.	Exposes soil to moderate degree.

Item	Method of Control: Anchor Chaining	Cutting, Beating, or Shredding	Harrowing
Kill of big sagebrush.	60-80 percent of old rigid brush, 10-20 percent each additional time over; 10-40 percent of young flexible brush.	50-90 percent of large old; 30-60 percent of young flexible.	30-70 percent of old rigid; 10-30 percent of young flexible.
Kill of associated undesirable plants.	Not effective on sprouting perennials or on annuals.	Not effective on sprouting shrubs or herbaceous species.	Not effective on sprouting shrubs or annuals.
Effect on desirable forage plants.	Nonsprouting shrubs are damaged; sprouters recover; little damage to herbaceous species.	Little damage to herbaceous plants; nonsprouting shrubs damaged.	10-20 percent of bunchgrasses uprooted; damage to bitterbrush slight.
Ease of seeding after treatment.	Broadcast before second chaining, or drill after final chaining where feasible.	Broadcast before cutting or heating heavy brush; drill after treating light brush.	Seed broadcast ahead of harrow well covered; drilling difficult.
Adaptability to terrain and soil.	Feasible on all soils and on slopes exceeding 30 percent. Breakage rare.	Limited to sites without protruding rocks.	Particularly suited to rocky ground and rough terrain.
Availability of equipment.	Commercially available through coastal salvage companies, or new.	Commercially available.	Not commercially available; can be built in machine shops.
Effect on erosion hazard.	Erosion usually decreased when approximate contours followed.	Mulch left decreases hazard.	Usually decreases hazard.

Source: Pechanec et al. 1965

Mechanical Methods of Release

Following are some common mechanical procedures.[1]

Mowing and Disking. Disking can be accomplished without mowing, to break up stands of sod-forming grass too dense for use by ground-dwelling wildlife, or after mowing, to help prevent regrowth of woody vegetation. Disking may be needed every 3 or 4 years. Mowing and disking sod should begin after July 15 when ground nesting is finished. Rotary mowers vary in size and pattern, having two to four blade designs. The heavy "brush hogs" can cut off and chop up any tree the tractor pulling it can run over. Mowers and disks must be matched with the tractor pulling them.

Shearing Blades and Chainsaws. To remove larger trees, an angular shearing blade can be bolted to the lower edge of a bulldozer's blade to slice through trees up to 8 inches diameter at breast height (d.b.h.). Chainsaws, which come in various sizes, must be used on larger trees. Operators should follow standard procedures.

Hula Dozer. The hula dozer (Figure 4-1) consists of 100 to 125 drawbar horsepower, crawler-type tractors with a "hula dozer" blade. The blade consists of hinged pusher bars and hydraulic tilting attachments. The pusher bar is used to tip trees, while the corner of the blade is used to lift them from the ground. Hula dozing is economically advantageous in areas where target trees are clustered and clusters are widely spaced, or where trees do not exceed 100 per acre. This method is used primarily where it is desired to leave stands of browse plants undamaged.

Shredding. Wood chipping machines, or shredders, can leave a site almost devoid of brush or slash. They are of rotary blade or roto-beater design and usually mounted to rubber-tired or crawler tractors. The mulch that remains helps prevent erosion and usually does not smother undergrowth. Shredders are useful for preparing forest sites and rights-of-way (Larson 1980).

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[1]Equipment used to treat areas for release from competition is described in Plummer et al. (1955, 1968), Sampson and Jesperson (1963), Box and Powell (1965), Pechanec et al. (1965), USDA Forest Service (1965), Vallentine (1971), Atlantic Waterfowl Council (1972), Burger (1973), Roby and Green (1976), Green (1977), and Larson (1980). Roby and Green (1976) and Larson (1980) compared specifications for rubber-tired tractors and crawler tractors and described techniques, capabilities, and limitations, with illustrations of revegetation equipment.

Chaining. Chaining consists of dragging a heavy chain (Navy surplus anchor, destroyer, or cruiser chain) through vegetation to break off or uproot plants. The best is the Ely chain, constructed by welding hard-surfaced rails or hard steel bars, 1 inch thick and 3 to 4 inches wide, to every link or third link. The bar ends should extend 4 to 5 inches beyond the links. The general procedure is for two tractors, one attached to each end of the chain, to travel on a parallel course spaced 60 to 100 feet apart. Additional disturbance can be gained with one tractor moving ahead of the other, so that the chain rides in a "J" pattern (Roby and Green 1976).

The spacing is dependent upon density of vegetation, weight and length of the anchor chain, size of tractor, and topography (Figure 4-2). In general, tractors should be spaced apart one-half to two-thirds the length of the chain (Larson 1980). Lengths of 200 to 500 feet are common (Vallentine 1971). Ordinarily, tractors with a minimum of 110 horsepower on the drawbar are used. The chain size is dependent upon the degree of kill desired. For dense stands of target species with little desirable understory, a heavy anchor chain weighing about 100 pounds per link achieves the best results (Figure 4-3). Dense young stands of trees or brush require a heavier chain than older stands, because the chain must ride close to the ground. Where it is desirable to leave a fairly dense residual stand of browse plants, 27- to 40-pound links should be used. A better kill is ensured by chaining when soil moisture is lowest, or when the first several centimeters of the soil are frozen. Chaining is most effective in removing mature, nonsprouting, even-aged, single-stemmed species like pinyon, most junipers, and other conifers (Vallentine 1971). It is not efficient in removing young, willowy trees.

Darr and Klebenow (1975) and O'Meara et al. (1981) found lower wildlife populations for some time after chaining in some areas. Such effects can be minimized by using lighter weight chains, selectively retaining trees with cavities, and limiting the widths of cleared areas to 660 feet (Robinson and Bolen 1984). Single trees or islands of unchained trees should be left to simulate natural openings of the landscape (Cain 1971). Chaining can create a good seedbed for aerial broadcast seeding. In areas planned for twice-over treatment along with aerial seeding, the second pass should be timed so that it will cover the seed.

Cabling. Cabling is suited to areas where it is planned to save residual stands of desirable shrubs and herbaceous cover, and where the competing target species are not young and willowy. Cabling is essentially the same process as chaining, except that a cable 150 to 200 feet long and 1.5 inches thick is used in place of a chain.

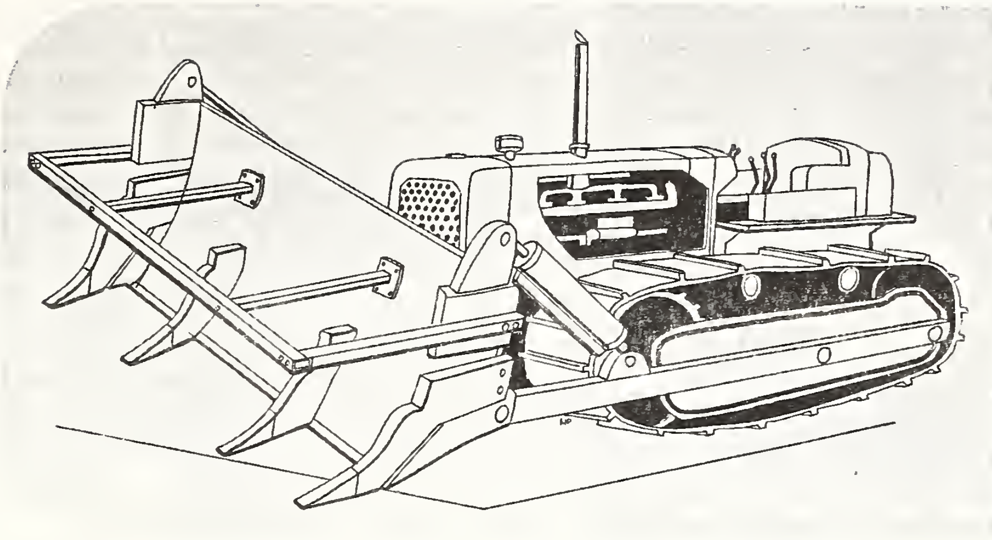
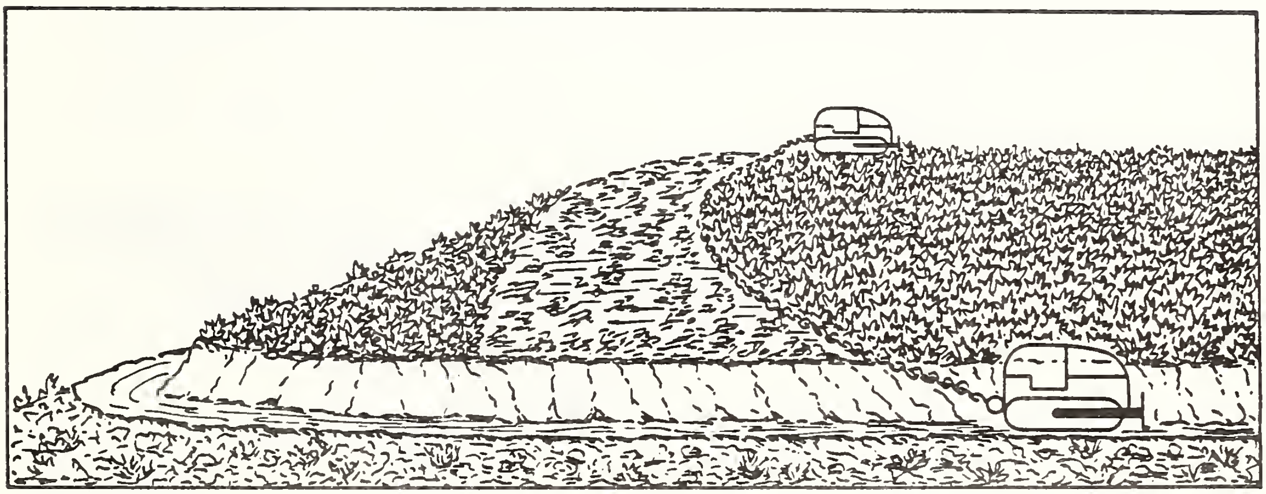


Figure 4-1. Hula dozer.

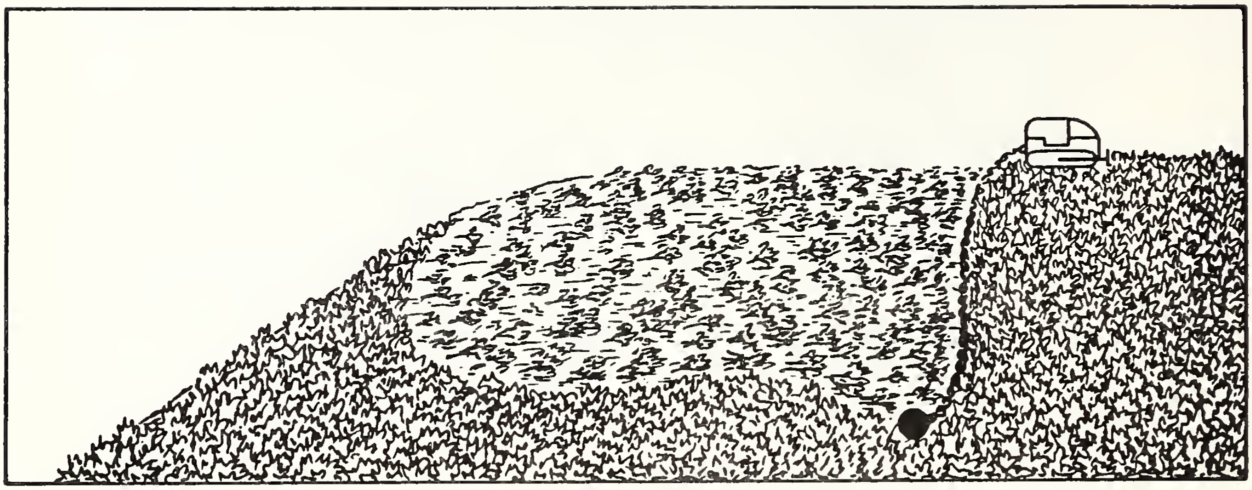
Source: Vallentine 1971



Some steep slopes between road and ridgetop can be worked with the modified chain. The lower tractor, on the road, should be leading to be clear of rolling material knocked loose by chain.

Figure 4-2. Chaining.

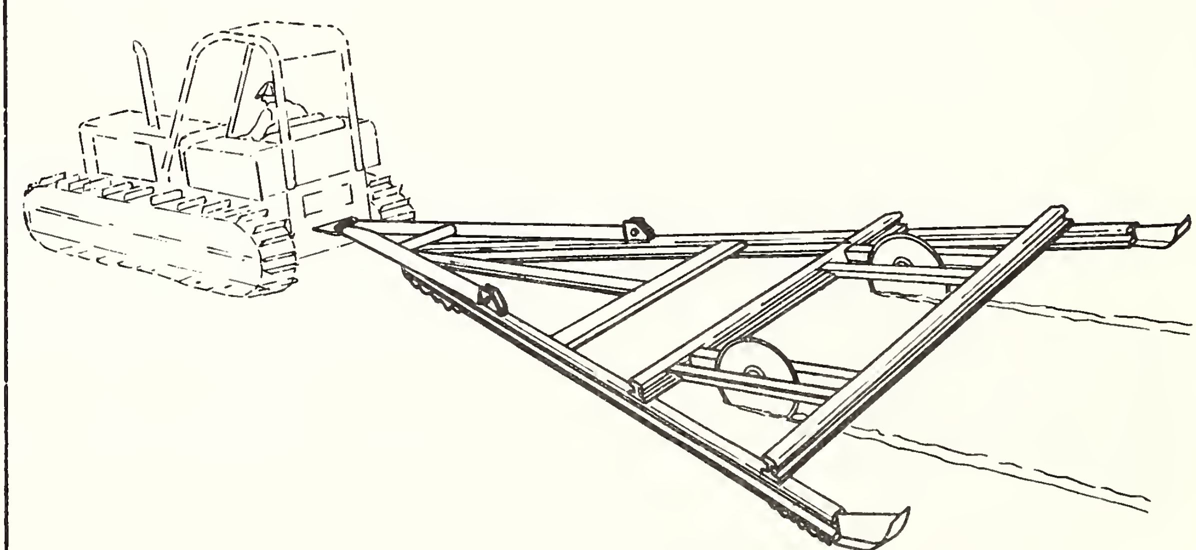
Source: Roby and Green 1976



The optimum terrain for a ball and chain operation is a long, straight ridge with steep uniform side slopes.

Figure 4-3. Ball and chain.

Source: Roby and Green 1976



The "A" rail.

Figure 4-4. Railing.

Source: Larson 1980

Railing. Railing consists of dragging railroad rails behind a tractor to crush and break off or uproot shrubs, allowing herbaceous forage plants to increase (Figure 4-4). It is especially effective when combined with herbicide treatment. Three recommended designs are the A-rail, the Supp rail, and the rail drag. Railing has been effective on prickly pear, big sagebrush, and other shrubs (Vallentine 1971, Larson 1980). Railing is most effective when vegetation and soil are dry and the ground is level. Railing twice over, then repeating 6 to 12 months later, is most effective.

Harrowing. Pipe harrows are spiked pipes attached to a spreader bar with swivels to allow the pipes to rotate and clean themselves of trash. Harrowing is used to thin low, brittle shrubs, scarify the soil, and cover broadcast seed. It is effective in rocky areas. Two passes are best.

Scalping. Scalping consists of scraping plants and part of the top layer of soil from planting sites. It is a simple and highly effective method of removing vegetation and most of the weed seeds in the surface soils. Of the many scalping methods, the simplest uses a hand hoe and the fastest and least expensive uses mechanical equipment. Mechanical scalping is limited to terrain that can be negotiated by tractor or jeep.

A Hansen seeder equipped with a wide moldboard plow is a practical method for scalping and planting gentle slopes free of rocks. On steeper slopes, a blade mounted on a three-point hydraulic hitch on the rear of a tractor often is used so that it can be raised and lowered at will. The blade is dropped for about 6 feet, then raised. The width of a scalp should exceed 24 inches, and it should be deep enough to remove the existing vegetation.

Hand scalping is effective on steep slopes and rocky areas. Scalp areas 2-1/2 feet square and at least 2 inches deep or deeper than the effective depth of the annual roots are cleared with the hoe. Heavier, narrower hoes are required for rocky, compact soils with perennial vegetation.

Material scraped off by scalping is piled on the lower side of the plot to form a catch basin. Sloughing of the soil into the scalp from its upper edge is common on slopes steeper than 50 percent. Sloughing is minimized by gradually increasing the scalping depth as the hoe is pulled downhill rather than by vertically chopping. The maximum slope on which scalps are stable in loose granite soil is about 65 percent. Heavier soils can be scalped on slightly steeper slopes.

Conventional Tillage Implements. Where soil and vegetative conditions justify, plowing may be used to eliminate competitive vegetation (Plummer et al. 1968). Disk-type plows, such as heavy offset-disk or wheatland, are good for controlling nonsprouting

species on soils with relatively few rocks. The brushland plow is best for rough, moderately rocky areas.

Plowing to a depth of 3 to 4 inches is recommended for most non-sprouting plants such as sagebrush. Plowing to depths of 4 to 6 inches is required to eradicate plants that spread by underground root stocks or from the crown. A heavy-duty plow is required to eliminate root-sprouting species.

The Holt plow is effective in reducing competition on slopes up to 40 percent where watershed measures also are needed. It will construct a continuously contoured furrow in either direction. This double disc furrower is attached to a crawler-type tractor by means of a specially built, three-point hitch. The depth and angle are controlled by a hydraulic ram. The tractor must have more than 100 horsepower on the drawbar to handle the Holt plow effectively.

Girdling. Trees are girdled by removing a strip of bark and outer xylem completely around the tree, with hand axe or saw or with a mechanically powered girdler (Vallentine 1971). Girdling in spring and summer is slightly more effective than in winter or fall. Girdling may be more effective than clearcutting against sprouting species, and is generally more effective on larger trees, as small trees are more apt to sprout.

Chemical Methods of Release

Generally, chemical treatment is less expensive than mechanical treatment, but more expensive than burning. One factor complicating chemical treatment is that most wildlife ranges support a mixture of shrub species that differ in sensitivity to chemicals.

What To Apply. Picloram and 2,4-D are most commonly used for range improvement (Evans et al. 1983), although other herbicides are used (Tables 4-2 and 4-3). Hamel (1983) listed target plants for specific herbicides with mixing ratios, application times, and rates.

Check with Forest or District silviculturalists or County Extension agents for the latest herbicide recommendations. The U.S. Environmental Protection Agency (1974 plus updates) lists all federally approved herbicides. In addition, one agency in each state participates in pesticide regulation, certifies pesticide applicators, and may have special registration and use requirements for pesticides. Miller and Craig (1979) and Newton and Knight (1981) described uses and application of various pesticides. Herbicides are among the least hazardous of pesticides, but routine safeguards include following all directions and restrictions shown on the pesticide label, storing pesticides only in the original container, disposing of excess chemicals properly, and cleaning equipment after use (Vallentine 1983). Hudson et. al (1984) described toxicity of pesticides to wildlife. Herbicides are classified into four toxicity classes for humans based on LD_{50} values (Table 4-4).

Table 4-2. Properties of herbicides used on rangeland or proposed for range use.

Common Name (Trade name)	Group and Type of Herbicide	Uses and Restrictions[a]	Range and Pasture Uses; Comments
Amitrole (Amino-triazole and Weedazol)	Triazole; foliage, nonselective, translocated.	Noncropland use principally.	Used on Canada thistle, horsetail, leafy spurge, shitetop, cattails, poison ivy. Persists 2-4 weeks in soil.
Atrazine (AAtrax)	Triazine; selective, soil sterilant.	Noncropland use; experimental on range.	Kills annual grasses and shows promise for chemical fallow on range. Persists for over 1 year in soil. Has increased protein content in perennial grasses.
Dalapon (Dowpon and Baspafon B)	Alaphatic; translocated, selective, foliage.	Pasture or noncropland use.	Foliage spray on emerged aquatics such as cattails and rushes, also medusahead and foxtail barley. Nonvolatile. Persists in soil up to 2-6 weeks.
Dicamba (Banvel)	Benzoic; selective, translocated, foliage or soil.	Cleared for pasture and range at rates up to 8 lb. active per acre.	Controls difficult plants such as Russian knapweed, Canada thistle, leafy spurge. Also useful in brush control. Persists in soil for up to a few months. Nonvolatile.
2,4-D (several trade names)	Phenoxy; selective, translocated, foliage.	Pasture and range.	Highly effective as foliage spray on many broad-leaved herbaceous plants and some shrubs. 2,4-D amine used in frill cuts. Persists in soil for 1-4 weeks. Volatility depends on chemical form.
Fenac (Fenac)	Phenylacetic; translocated by roots, selective, temporary soil sterilant.	Spot treatment on range.	Used on Canada thistle, leafy spurge, Russian knapweed, and woody plants. Persists 1 year or longer in soil.
Glyphosate (Roundup)	Alaphatic; nonselective, translocated, foliage.	Mostly experimental on range; broad spectrum herbicide.	Shows promise in brush control but also kills desirable grasses and forbs. Shows promise in killing undesirable grasses such as foxtail barley or saltgrass. Persists 1-3 weeks in soil.
Karbutilate (Tandex)	Carbamate and substituted urea; nonselective, soil applied.	Experimental on range; noncrop herbicide.	Effective on many plant species; injurious to forage plants; persists several months in soil.
Paraquat Ortho (Paraquat)	Bipyridyl; selective to nonselective, contact, foliage.	Use as spot treatment on noncropland or pasture or range renovation.	Major interest in grass seedbed preparation by application at 1/4-1 lb. per acre just before seeding. Rapid acting, nonvolatile. Soil contact inactivates. Has minor effect on broadleaf perennials. Low rate (0.2 lb. per acre) chemically cures but does not kill perennial grasses.

[a]Registration of herbicides for range and pasture uses and the accompanying restrictions are subject to continual change. Current clearance and restrictions at both State and Federal levels should be checked and complied with.

Source: Vallentine 1983

Table 4-2 (continued). Properties of herbicides used on rangeland or proposed for range use.

Common Name (Trade name)	Group and Type of Herbicide	Uses and Restrictions[a]	Range and Pasture Uses; Comments
Picloram (Tordon)	Picolinic; selective, translocated, foliage or soil.	Noncropland, spot treatment. Limited clearance in some States for range use.	Effective on leafy spurge, Russian knapweed, low and tall larkspur, whorled milkweed, and also many shrubs such as rabbitbrush and oaks. Nonvolatile. Rates over 1 lb. per acre may persist for 2 or 3 years. Often synergic with phenoxy herbicides.
Silvex or 2,4,5-TP (Kuron, Weedone)	Phenoxy; selective, translocated, foliage.	Pasture and range clearance. Do not use on newly seeded pasture or range.	Plant control including oaks, maples, yucca, cholla, pricklypear, tall larkspur, saltcedar, and Dalmation toadflax. Persists 2-5 weeks in soil. Also for basal stem or stump treatment.
2,4,5-T (several)	Phenoxy; selective, translocated, foliage.	Rangeland clearance.	Foliage spray on woody plants including oak, maple, mesquite, elm, ceanothus, cholla, roses, huisache, pricklypear, and yucca. Also used in basal trunk spray, frills, and stump treatment; persists 4-8 weeks in soil.
2,3,6-TBA (Benzac, Trysben)	Benzoic, nonselective, soil sterilant.	Noncropland or spot treatment on range. Not for food or feed crops.	Used on leafy spurge, Canada thistle, Russian knapweed. At high rates persists 18-24 months.
Tebuthiuron (Spike, Graslan)	Substituted urea; nonselective, translocated, soil sterilant.	Experimental on rangelands; cleared for range use in some States.	Holds promise for controlling woody plants. Persists up to several months. Spot apply or broadcast as pellets.
Triclopyr (Garlon)	Phenoxy-picolinic; selective, translocated, foliage or soil applied.	Experimental on rangelands.	Shows promise on broadleaf weeds and shrubs including oaks and other root sprouters. Also effective in basal spray and trunk injection. Degraded rapidly in soil.

[a]Registration of herbicides for range and pasture uses and the accompanying restrictions are subject to continual change. Current clearance and restrictions at both State and Federal levels should be checked and complied with.

Source: Vallentine 1983

Table 4-3. Trade and chemical names of some commonly used forestry herbicides.

Trade name	Common chemical name of active ingredient	Chemical name
Dowpon M	Dalapon	2,2-dichloropropionic acid
Aatrex 80 W	Atrazine	2-chloro-4-ethylamino-6-isopropylamino-s-triazine
Esteron 4	2,4-D	2,4-dichlorophenoxyacetic acid
Roundup	Glyphosate	isopropylamine salt of N-(phosphonomethyl) glycine
Milogard	Propazine	2-chloro-4-,6-bis(isopropylamino)-s-triazine
Princep	Simazine	2-chloro-4,6-bis(ethylamino)-s-triazine
Asulox	Asulam	methyl sulfanilylcarbamate
Goal	Oxyfluorfen	2-chloro-1-(3-ethoxy-4-nitrophenoxy)-4-(trifluoromethyl) benzene
Modown	Bifenox	methyl 5-(2',4'-dichlorophenoxy)-2-nitrobenzoate
Spike	Tebuthiuron	1-(5-tert-butyl-1,3,4-thiadiazol-2-yl)-1,3-dimethylurea
Tordon	Picloram	4-amino-3,5,6-trichloropicolinic acid
Velpar	Hexazinone	3-cyclohexyl-6-(dimethylamino)-1-methyl-1,3,5,-triazine-2,4(1H,3H)dione

Source: Heidmann 1984

<u>How To Apply</u>. Vallentine (1983) outlined the methods available to apply herbicides:

- I. Foliage application
  - A. Spray
    - 1. Broadcast
      - a. Aerial (fixed-wing or helicopter, usually on areas larger than 100 acres)
      - b. Ground
        - (1) Nondirectional (boom sprayers and mist sprayers)

Table 4-4. Pesticide toxicity classes and LD_{50} values for some common materials.

Toxicity Class	LD_{50} (mg/kg)	Required on Label	Examples	LD_{50} (mg/kg)	Amount Required to Kill 160-Pound Individual (gm)	(oz)
Highly toxic	1-50	Danger, Poison, Skull and Crossbones	Methyl bromide	35	2.54	0.09
		KEEP OUT OF REACH OF CHILDREN				
Moderately toxic	50-500	Warning! KEEP OUT OF REACH OF CHILDREN	2,4-D	300	21.77	0.77
				1,000	72.57	2.56
			2,4,5-T	481	34.91	1.23
			Paraquat	157	11.39	0.40
Slightly toxic	500-5,000	Caution, KEEP OUT OF REACH OF CHILDREN	Aspirin	1,200	87.09	3.07
			Atrazine	3,000	217.72	7.68
			Cacodylic acid	830	60.24	2.12
Practically nontoxic	Above 5,000	KEEP OUT OF REACH OF CHILDREN	Simazine	5,000	362.87	12.80
			Picloram	8,200	595.11	20.99
			Dalapon	9,330	677.12	23.88
			Amitrole	24,600	1,785.33	62.98

Source: Heidmann 1984

(2) Directional
   (a) In-row (rowed plants physically protected from spray)
   (b) Strip (chemical seeded preparation for interseeding)

B. Wipe-on (rope wicks, rollers, sponge bars as on end of drip torch)

C. Dust (unimportant on range)

II. Stem application (individual plant)
   A. Trunk base spray (may be enhanced by use of frills or notches)
   B. Trunk injection
   C. Cut stump treatment

III. Soil application
   A. Broadcast (spray, granules, or pellets)
   B. Grid ball (spaced placement of pellets)
   C. Individual plant
      1. Soil injection (liquid)
      2. Soil surface placement (around stem base or spread under canopy)

Picloram pellets (30 to 50) applied by hand at the base of stems or suckers during the growing season resulted in adequate kill of quaking aspen, willow, balsam fir, and tag alder to maintain forest openings in Wisconsin (McCaffery et al. 1974). In wildlife areas, it may be desirable to develop 10 percent of the forested areas into openings by selective treatment with picloram pellets. By examining aerial photos for breaks in the canopy and by walking compass transects through the forest in search of sunlight penetrating the canopy, prospective areas can be identified.

The most practical herbicide for brush control on sagebrush-grass rangelands is 2,4-D (Evans et al. 1983). Big sagebrush usually is controlled by 2 pounds per acre (lb/ac). Mixed stands of sagebrush and green rabbitbrush can be controlled with 3 lb/ac or a mixture of 0.5 lb/ac of picloram and 2 lb/ac of 2,4-D. Mixed stands of big sagebrush and the desirable bitterbrush may be sprayed with 2,4-D at the standard sagebrush control rate without serious loss of bitterbrush whether bitterbrush is in bloom or not.

Broadcast spray application, most commonly used on rangelands, can be made from ground rigs or aircraft (Vallentine 1983). With ground rigs, spray volume may vary from 5 to 40 gallons per acre (gal/ac) depending upon need, but 1 gal/ac is common. With aircraft, spray volume is 1 to 3 gal/ac and even as low as 0.25 to 0.5 gal/ac in some cases.

<u>When To apply</u>. Vigorous growth is essential for effective kills. Herbicides are ineffective without adequate soil moisture to promote plant growth and to activate chemicals (Smith 1966). Thus,

spring and early summer are best for most species, but enough variation in phenology exists to generalize with caution. In the Southwest, the summer rainy season is best (Heidmann 1984). For green rabbitbrush, color infrared photography can be used to predict the optimum spray date (Young et al. 1976). Apply ground and aerial sprays with winds less than 10 miles per hour (mph) and 5 mph, respectively.

Where to apply. Areas where no desirable perennial grasses and forbs are available for release should not be treated, unless plantings are made. Aerial application within 200 feet or ground application within 50 feet of wetlands and key wildlife habitats should be avoided (Wenger 1984). To limit drift, coarse, oil-free sprays should be used.

Prescribed Fire

Fires increase the diversity of wildlife species present in an area by creating new habitats or expanding existing ones. Burned areas typically produce more browse, grasses and forbs, which benefit herbivores and the carnivores that prey on them (Wright and Bailey 1982). Prescribed fire can be combined with sharecropping in wildlife habitat management. Prescribed burning must be conducted by following instructions and adhering to the experience gained by others who have done prescribed burning. In drawing up plans, it is critical that advice be sought from those experienced in prescribed burning rather than from firefighters. Variables critical to good planning include wind speed, relative humidity, temperature, fuel load, fuel moisture, and topography.

Planning a Prescribed Burn. The USDA Forest Service uses a prescribed fire plan form (Figure 4-5) to be completed before, during, and after a burn. Following are outlined steps in planning a prescribed burn (FSM 5142.1).

(1) A description of the burn unit and the resource management objectives, including fuel reduction, to achieve by burning.

(2) Provision for public safety and protection of sensitive features. Include a safety and health hazard analysis (FSM 6740). The analysis shall include a determination as to whether employees shall carry emergency fire shelters.

(3) Source of funding and estimated costs.

(4) Range of acceptable results expected, expressed in quantifiable terms.

(5) A fire prescription, including weather factors and fuel conditions, necessary to achieve desired fire behavior (FSM 5143.3, items 6 and 9).

PRESCRIBED FIRE PLAN *(all items must be completed)*

A. Location and Administrative Information:

Ranger District ________________ FY _____ Purpose __________________

Acres _____ Mgmt. Code _____ Est. Cost _____ Compartment/Stand ________

Township _____ Range _____ Section _____

B. History of Previous Burn: *(List date and type of previous burns or fire and effects)*

C. Description of Burn Unit:

1. Overstory *(Forest type, mgt. type, stand condition class, age, basal area)*

2. Understory *(Forest understory description, age, etc.)*

3. Fuels *(Describe dead and live fuel types, age of rough, litter and duff depth, fuel loading (tons/acre by size class) and arrangement.*

4. Topography *(Describe average slope, aspect and soil condition. Indicate any active erosion, and the potential for erosion based on soil type)*

5. Chains of Line to Establish *(Indicate the amount of plowed and hand lines that will have to be constructed)*

D. Specific Objectives: *(Describe in terms of specific results desired in quantifiable terms. Explain in detail. Post burn evaluation should cover these objectives.)*

E. Special Considerations: *(Note any special considerations that may affect the timing and manner of how the block would be burned. These considerations include hardwood exclusions, public and private safety factors, protection of special features, VQO.) (Limitation in prescriptions or EAs.)*

1. Hazard Analysis: *(Refer to date and location of analysis or appropriate statement.)*

a. Fire Shelter required *(yes or no)*

2. Public Notification:

Name	Contact Method
(Adjacent landowners, interested parties, etc.)	*(Personal, telephone, radio, letter, TV, etc.)*
(Need to know basis)	

3. Coordination with other Resources: *(List resource by name)*

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Figure 4-5. Prescribed fire plan.

J. Prescribed Parameters, On-Site Observations and Fire Behavior Calculations:

Input Data (Enter in any order)		Reg. No.	PRESC* PARAM.	TEST FIRE	POST FIRING	POST FIRING	POST FIRING
2nd PGM 2 SBR R/S (Display = -4)							
Fuel Model NFFL Behavior							
NFDR Danger							
Shade Value	(value SBR SHADE)	60	xxxx				
Dry Bulb Temperature	(value SBR DB)	61					
Relative Humidity	(value SBR RH)	62					
1 H TL FM, %	(value SBR 1H)	28					
10 H TL FM, %	(value SBR 10H)	63	1/				
100 H TL FM, %	(value SBR 100H)	30	xxxx				
Live Fuel Moisture	(value SBR LIVE)	33	xxxx				
Midflame Windspeed, mph	(value SBR M WS)	79					
Direction (List all acceptable directions)							
Windward Percent Slope %	(value SBR PCTS)	80					
Projection Time, h	(value SBR PT)	81	xxxx				
Map Scale, in/mi	(value SBR MS)	82	xxxx				
Output data (Must be run in sequence below)							
Rate of Spread, ch/h	(A)	88	xxxx				
Heat per Unit Area, BTU/sq.ft.	(R/S)	90	1/				
Fireline Intensity, BTU/ft/s	(B)	53	1/				
Flame Length, ft	(R/S)	54					
Spread Distance, ch	(C)	42	xxxx				
Map Distance, in	(R/S)	43	xxxx				
Perimeter, ch	(D)	40	xxxx				
Area, acres	(R/S)	89					
Ignition Component	(E)	44					
Observed Flame Length			XXXXX				
Time of Year to Burn							
Type Fire to Use							
1/ Cumulative Severity Index							

*Required Items to be Completed at Time of Planning

1/Optional

Figure 4-5 (continued). Prescribed fire plan.

Q. Post Burn Evaluation: 1/ *(Refer to Prescribed Fire Monitoring and Evaluation Guide - October 1982)*

1. Date: *(Immediately after burn)* Date: *(Later date based on conditions)*

*2. Amount Litter Left (inches): ____________________

3. Understory Vegetation Consumed (%): *(Percent of vegetation consumed by fire)*

4. Scorch: % of Area with Crown Scorch of 25-50% ____ 50-70% ____ 75%+ ____

*5. Spotting: *(Yes or No - or relative statement)*

6. Tree Damage (insects, disease, mortality): *(Can damage be connected to fire?)*

7. Understory Kill of Undesired Vegetation (%): *(Refers to objective of burn) (Top kill of undesirable vegetation)*

*8. Any Smoke Management Violations: *(Information here may be useful for reference)*

9. Any Escape: *(List date and consequences, also residual smoke problems)*

*10. Any Complaints (explain): ____________________

11. Adverse Effects: *(Ask for review of some burn areas by resource specialist - visual, cultural, soils, wildlife, etc.)*

12. Restoration Needed: *(Refers to erosion)*

13. Objectives Met (results): *(Explain in detail to determine the economic and managerial value of the burn. Was burn within cost estimates - explain)*

Evaluation By: ____________________ Name ____________________ Date

(Recommendation for future evaluation): *(List future date and specific items)* ____________________ Date

Evaluation By: ____________________ ____________________ Date

*Evaluate Immediately After Burn

1/ Attach Additional Sheets as Necessary.

Figure 4-5 (continued). Prescribed fire plan.

(6) Firing, containment, mopup, and patrol procedures. Refer to FSH 5709.12 regarding procedures and safety requirements for use of helitorch equipped helicopters.

(7) Provision for preburn coordination and, where applicable, public involvement and burnday notification to appropriate individuals, agencies, and the public.

(8) Smoke management requirements.

(9) A postburn evaluation process.

(10) Specific instructions on procedures if the fire exceeds prescription and line holding capabilities.

(11) The potential need for a test fire (FSM 5142.3). In prescribed fire plans for approved areas utilizing unplanned ignitions, a test fire is not required.

Regional Foresters may establish additional requirements as needed to achieve prescribed fire objectives.

Weather. To burn standing debris, wind speed should be at least 8 miles per hour (mph) (Britton and Wright 1971). To burn dead hardwood, top-kill shrubs, or volatile fuels, wind speed should be 8 to 15 mph (Wink and Wright 1973). Best wind speeds for chaparral are 5 to 8 mph; over 20 mph, firebrands (glowing embers) and tumbleweeds become problems. Burning is risky on calm days because "light and variable" winds often are forecast then; a steady wind is best.

In general, relative humidity should be 20 to 40 percent (Britton and Wright 1971; Lindenmuth and Davis 1973), unless winds are less than 6 mph and temperatures are below 40° F, or when burning pinyon-juniper and sagebrush-grass, which requires a relative humidity below 20 percent. Below 60° F, danger from firebrands is low, but increases exponentially above that (Bunting and Wright 1974).

Fuel. The more fine fuel present, the more flexibility there is in prescriptions. Generally, to burn grasslands with or without shrubs, at least 600 to 1,000 lb/ac of fine fuel is needed (Wink and Wright 1973; Beardall and Sylvester 1976). The closer the shrubs grow together, the less fine fuel is needed. Green chaparral without forbs and grasses will not burn well (Cable 1975). Big sagebrush needs a 20 percent canopy and live juniper needs a 35 to 40 percent canopy to burn well (Wright and Bailey 1982). In forests, sparse or moist duff, needles, and grass can result in underburn.

Low-volatile fuels are relatively safe to burn, but high-volatile fuels are explosive. High-volatile fuels can cause firebrand problems and require firelines up to 500 feet wide and also require a thorough knowledge of weather (Green 1970; Bunting and Wright 1974). Chaparral, conifers, dead aspen, and dead juniper are high-volatile fuels; grasses and hardwoods are low-volatile fuels; sagebrush, oaks, live aspen, rough beneath southeastern pines, and slash are moderately volatile. Moisture of fire fuels is related to relative humidity and should be between 7 and 20 percent (Countryman 1964, 1971; Mcbley et al. 1973). Species of grasses, grasslike plants, forbs, and shrubs vary in their reaction to fire (Tables 4-5, 4-6, and 4-7).

Topography. Fires burning up slopes burn faster; fires burning up a 20 to 40 percent slope will burn twice as fast as on level terrain (Southwest Interagency Fire Council 1968). Burns should be made with ridges, not across them, because firewhirls usually develop on the lee side and might throw large firebands ahead of the leading edge of the fire, causing spot fires (Countryman 1971). Firewhirls also can develop on calm days on flat terrain, if the entire perimeter is lit (Haines and Updike 1971), or if headfires are burned into backfires. Other potential sites for firewhirls are curves in topography, edges of roads, corners of burns, and heavy fuel loads on forest sites.

Firelines. A 5- to 20-foot fireline is wide enough in slash, grassland litter, and southeastern pine. In sagebrush-grass (use moderately volatile fuel), a fireline 250 feet wide is best. In high-volatile fuels, a 500-foot-wide fireline is best. On ridgetops, firelines can be narrower, especially if the south-facing slope is being burned and the north-facing slope is more moist, which is likely.

Firelines usually are dozed or plowed because of their versatility in varying terrain and vegetation. They should always be plowed away from the area to be burned. To minimize the visual effects, the wetline technique works in light to moderate grasslands (Dube 1977, Martin et al. 1977), as does a sprinkler wetline system on broadcast burns in lodgepole pine slash (Quintilio 1972). Chemical fire retardants are possible alternatives. Liquid explosives have been used in Idaho and Montana (Dell and Ward 1970).

Table 4-5. Summary of fire effects on major grass and grasslike species of the sagebrush and pinyon-juniper zones of the Intermountain Region.

Species	Growth Form	Response to Fire	Postburn Recovery Time[a]	Comments
Big bluegrass	Bunchgrass	Slightly to moderately damaged	Rapid to very rapid	Bluegrasses are mostly small bunchgrasses with densely clustered, medium- to fine-textured leaves. Little injury occurs with late summer or fall burns; most damage results from spring burns after initiation of growth. Heavy seed crops produced after burning.
Cusick bluegrass	Bunchgrass	Slightly to moderately damaged	Rapid to very rapid	
Muttongrass	Bunchgrass	Slightly to moderately damaged	Rapid to very rapid	
Nevada bluegrass	Bunchgrass	Slightly damaged	Rapid to very rapid	
Sandberg bluegrass	Bunchgrass	Undamaged to slightly damaged	Rapid to very rapid	
Kentucky bluegrass	Rhizomatous sodgrass	Slightly damaged	Rapid to very rapid	Increases primarily by vegetative spread.
Cheatgrass	Annual	Undamaged	Rapid to very rapid	Soil seed reserves are reduced and litter loss results in decreased plant density in the first year after fire. However, plants are large and produce abundant seed. Stand reduction is short-lived, and density may exceed preburn levels within a few years.
Idaho fescue	Bunchgrass	Slightly to severely damaged	Slow to rapid	Densely tufted and fine-stemmed. Can sustain severe damage from hot summer or fall burns; but spring or fall burns with good soil moisture injure plants much less.
Indian ricegrass	Bunchgrass	Slightly damaged	Rapid	Slow to increase in density.
Junegrass	Bunchgrass	Undamaged	Rapid to very rapid	Small size and coarse-textured foliage result in little or no injury. Heavy seed production; may increase in density after burning.
Columbia needlegrass	Bunchgrass	Moderately damaged	Moderate to rapid	Densely tufted stems make the needlegrasses one of the least fire resistant bunchgrasses. Large plants are most severely damaged; but reduction in basal area is likely among all size classes.
Needle-and-thread	Bunchgrass	Severely damaged	Moderage to rapid	
Thurber needlegrass	Bunchgrass	Severely damaged	Moderate to rapid	
Western needlegrass	Bunchgrass	Moderately damaged	Moderate to rapid	
Douglas sedge	Rhizomatous	Undamaged	Very rapid	Responses appear to be related to open growth habit and regrowth from rhizomes. Threadleaf sedge responds like fine-stemmed, densely tufted bunchgrasses.
Threadleaf sedge	Tufted bunch	Severely damaged	Moderate to slow	
Bottlebrush squirreltail	Bunchgrass	Undamaged to slightly damaged	Rapid to very rapid	Coarse-stemmed, loosely tufted. One of the most fire resistant bunchgrasses. Basal areas may be reduced from burning in dry years; but it may increase.
Bluebunch wheatgrass	Bunchgrass	Slightly damaged	Rapid to very rapid	Bluebunch wheatgrass is susceptible to injury when burned in dry years. Rhizomatous species may increase density. Other wheatgrasses are difficult to burn when seeded in monocultures.
Crested wheatgrass	Bunchgrass	Undamaged	Rapid	
Tall wheatgrass	Bunchgrass	Undamaged	Rapid	
Intermediate wheatgrass	Weakly rhizomatous	Undamaged	Rapid	
Thickspike wheatgrass	Rhizomatous	Undamaged	Rapid	
Western wheatgrass	Rhizomatous	Undamaged	Rapid	

[a]Postburn recovery time is based on the number of years required to regain preburn frequency or canopy coverage: slow = greater than 10 years, moderate = 5 to 10 years, rapid = 2 to 5 years.

Source: Wright et al. 1979, Volland and Dell 1981 *in* Young 1983

Table 4-6. Summary of relative response to fire of forbs in sagebrush grasslands of Upper Snake River Plains of Idaho.

Severely damaged	Slightly damaged	Undamaged
Hairy fleabane	Astragalus	Arrowleaf balsamroot
Hoary phlox	Matroot penstemon	Common comandra
Littleleaf pussytoes	Monroe globemallow	Common sunflower
Low pussytoes	Pinnate tanseymustard	Coyote tobacco
Mat eriogonum	Plumeweed	Douglas knotweed
Unita sandwort	Red globemallow	Flaxleaf plainsmustard
Wyeth eriogonum	Sticky geranium	Flaxweed tanseymustard
	Tailcup lupine	Foothill deathcamas
	Tapertip hawksbeard	Gayophytum
	Tongueleaf violet	Goldenrod
	Tumblemustard	Goosefoot
	Wavyleaf thistle	Lambstongue groundsel
	Whitlow-wart	Longleaf phlox
	Wild lettuce	Orange arnica
		Pale alyssum
		Purpledaisy fleabane
		Russian thistle
		Velvet lupine
		Western yarrow
		Wild onion

Source: Pechanec et al. 1954 _in_ Young 1983

Ignition. Ignition methods (Figure 4-6) are described in detail by Davis (1959), Dixon (1965), Southwest Interagency Fire Council (1968), Sando and Dobbs (1970), and Mobley et al. (1973), and when various methods were used is described in Wright and Bailey (1982). Headfires (which move with the wind) are best to kill shrubs and trees (Fahnestock and Hare 1964, Gartner and Thompson 1972, Sackett 1975), to burn down standing dead trees (Britton and Wright 1971), to burn low quantities of fine fuel (600 to 1,000 lb/ac), and to clean up debris and brush (Heirman and Wright 1973, Wink and Wright 1973). Backfires (which move against the wind) are used when fuel exceeds about 1,800 lb/ac to reduce heat damage to overstory, to conifers (Biswell et al. 1973, Mobley et al. 1973), and when weather is riskier than desired.

Strip-headfires usually are used to burn the fireline or when backfires move too slowly and headfires would be dangerous or otherwise undesirable. Area (spot) ignition (Fenner et al. 1955, Schimke et al. 1969) is used to set the entire area, causing a fire to move toward the middle. Center ignition (Beaufait 1966) is similar to area ignition except the center is lit first, and fire intensity

Table 4-7. Summary of fire effects on major shrub species of sagebrush and pinyon-juniper zones of the Intermountain Region.

Species	Preburn Regeneration	Response to Fire	Postburn Regeneration; Recovery Time[a]	Comments
Antelope bitterbrush Cliffrose	Heavy seed, animal dispersed	Moderately to severely damaged	Seed germination from rodent caches, basal stem sprouting; slow	Effect of fire on bitterbrush determined by growth form--decumbent form may sprout vigorously, upright form is a weak sprouter. Severely damaged by summer and fall burns. Spring burns enhance sprouting; burn when wet.
Big sagebrush Black sagebrush Low sagebrush	Light seed, wind dispersed	Severely damaged	Seed germination non-sprouting; slow to rapid	Frequent, heavy seed crops; readily dispersed over large areas. Good seed production prior to burning speeds reinvasion, especially in poor condition ranges. Big sagebrush subspecies important relative to postburn community response. Black and low sagebrush rarely burn due to low fuel loads--can be used as fuel breaks.
Threetip sagebrush	Light seed, wind dispersed	Slightly to severely damaged	Resprouts (variable), seed germination; moderate to rapid	Sprouting is strongest when burned with moist soils. Weak resprouting reported in Idaho; strong response reported in Oregon.
Silver sagebrush	Light seed, wind dispersed	Slightly damaged to unharmed	Vigorous sprouting, seed germination; moderate to rapid	May be difference in degree of resprouting between the two subspecies.
Greasewood	Light seed, wind dispersed	Slightly damaged to unharmed	Vigorous basal stem and some root sprouting; rapid	Vigorous resprouting may result in increased density of stems. Poor seed production the first year after burning. Some stands burn infrequently if at all due to low amounts of fine fuels.
Rubber rabbitbrush Green rabbitbrush Spineless horsebrush	Light seed, wind dispersed	Unharmed to enhanced	Vigorous stem sprouting, seed germination; rapid to very rapid	Reproduces abundantly from heavy seed crop, especially in low condition ranges. Rubber rabbitbrush may be more susceptible to injury, especially if burned after heavy grazing or in early summer. Horsebrush is toxic to sheep.
Broom snakeweed	Light seed, wind dispersed	Severely damaged	Seed germination, weak resprouting; moderate to rapid.	May be completely removed from an area, but new plants invade open areas rapidly by seed.
Gambel oak	Heavy seed, gravity dispersed	Enhanced	Vigorous stem and root sprouting; very rapid	Fire stimulates suckering and thickens stands. Tends to thin out when protected from fire.
Common snowberry Mountain snowberry	Rhizomes, seed	Slightly damaged to unharmed	Weak to vigorous resprouting from basal buds and rhizomes; moderate to rapid	May be enhanced by cool fires, but hot fires can damage shallow rhizomes. Mountain snowberry is a weak sprouter.

[a]Postburn recovery time is based on the number of years required to regain preburn frequency or canopy coverage: slow = greater than 10 years, moderate = 5 to 10 years, rapid = 2 to 5 years, very rapid = 1 to 2 years.

Source: Wright et al. 1979, Volland and Dell 1981 in Young 1983

Table 4-7 (continued). Summary of fire effects on major shrub species of sagebrush and pinyon-juniper zones of the Intermountain Region.

Species	Preburn Regeneration	Response to Fire	Postburn Regeneration; Recovery Time[a]	Comments
True mountain mahogany	Moderately heavy seed, wind dispersed	Slightly damaged	Vigorous sprouting, seed germination; recovery time unknown	Little information available on this species. Recovery time probably moderate to rapid, based on its sprouting response.
Curlleaf mountain mahogany	Moderately heavy seed, wind dispersed	Moderately to severely damaged	Seed germination, weak sprouting; recovery time unknown	Little information available on this species. Reported to be weak sprouter, but shoots died within 2 to 3 years. Recovery from seed probably slow to moderate.
Ninebark Ocean spray Spiraea	Light seed, wind dispersed	Unharmed to enhanced	Basal stem sprouting; moderate	Adapted to fire. Best response when burned with moist soils. Usually poor reproduction from seed.
Bittercherry Chokecherry Currant Rose Serviceberry	Heavy fleshy seed, animal	Unharmed to enhanced	Basal stem sprouting; moderate	Adapted to fire. Best response when burned with moist soils. Usually poor reproduction from seed except for currants that are heat scarified, and germination is stimulated.
Snowbrush	Heavy seed	Unharmed to enhanced	Vigorous sprouting from stems, seed is heat scarified; rapid	Seedling establishment enhanced by fall burns. Spring burns produce fewer resprouts. Common pioneer on high intensity burns.

[a]Postburn recovery time is based on the number of years required to regain preburn frequency or canopy coverage: slow = greater than 10 years, moderate = 5 to 10 years, rapid = 2 to 5 years, very rapid = 1 to 2 years.

Source: Wright et al. 1979, Volland and Dell 1981 in Young 1983

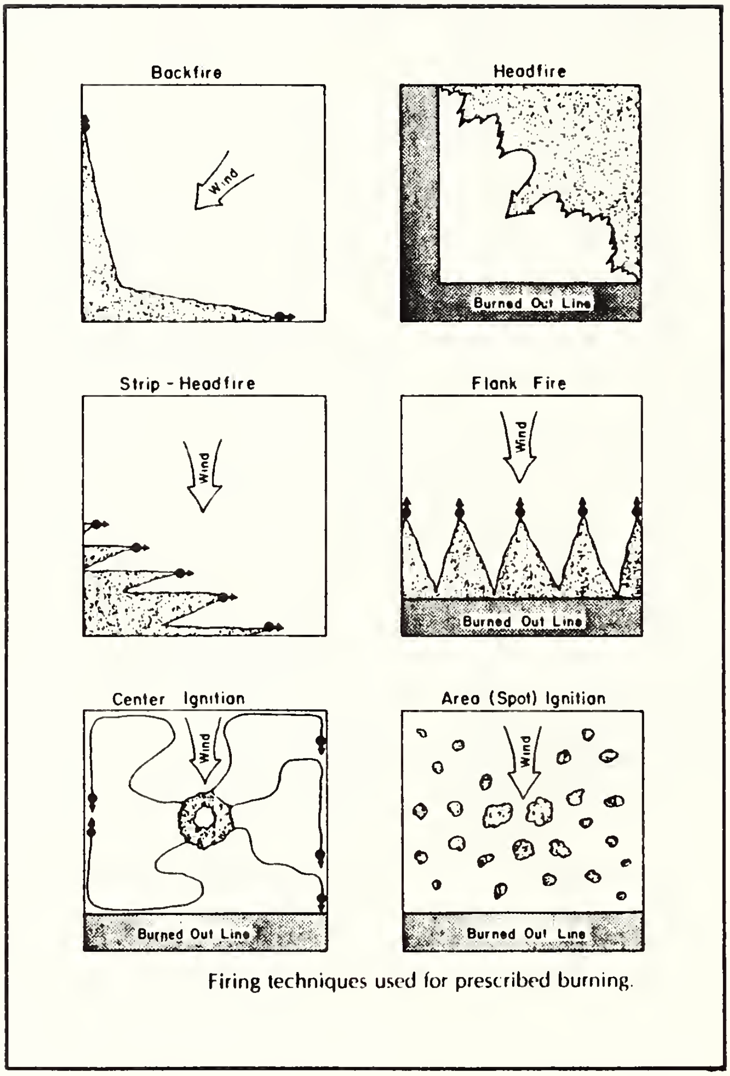


Figure 4-6. Firing techniques used for prescribed burning.

Source: Wright and Bailey 1982

increases more slowly. Generally, center, and at times, area ignition, are used to burn slash (clearcut, no overstory) in driving light winds. These types of ignition pull winds into the center of the fire, causing intense fires with only an occasional firebrand resulting.

Prescriptions for Different Fuel Types. Wright and Bailey (1982) generally described conditions and techniques for burning low-volatile, moderately volatile and highly volatile fuel types. Low-volatile fuels include semidesert grass-shrub, shortgrass prairie (Figure 4-7), mixed-grass prairie (Figure 4-8), tallgrass prairie (Figure 4-9), fescue prairie, marshes, and open stands of pinyon-juniper with grass understory.

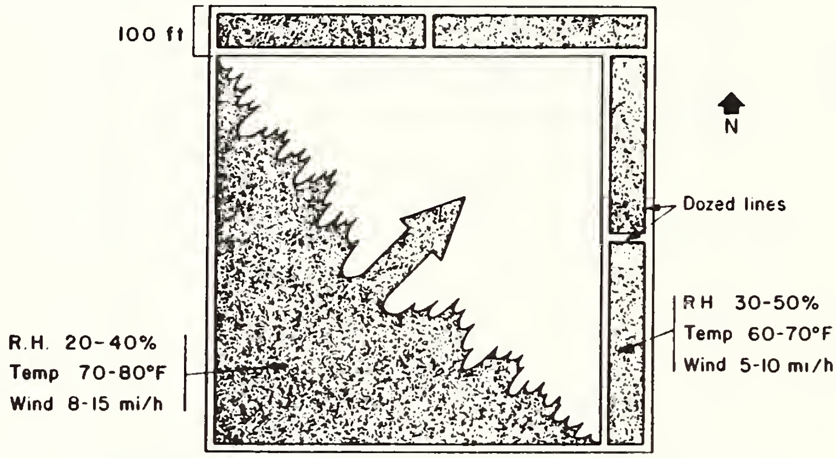
Some moderately volatile fuel types include big sagebrush-grass (Figure 4-10), big sagebrush, low sagebrush, sand shinnery oak-little bluestem, southeast pine (Figure 4-11), ponderosa pine (Figure 4-12), Douglas-fir, western larch, red pine, white pine, slash, and live aspen forest (Figure 4-13).

Some highly volatile fuel types described by Wright and Bailey (1982) are California chaparral (Figure 4-14), Arizona chaparral (Figure 4-15), dozed juniper in mixed prairie (Figure 4-16), chained juniper in mixed prairie (Figure 4-17), closed stands of pinyon-juniper with no grass (Figure 4-18), mixed pinyon-juniper-sagebrush, and chained juniper (Figure 4-19).

Biological Methods of Release

Controlled Livestock Grazing. Although grazing livestock near some wildlife plant species can be detrimental, controlled grazing can be beneficial in releasing desired plants from competition. Generally, most grazing systems fall into three categories (Bryant et al. 1982): (1) high-intensity/low-frequency grazing system (for example, one herd at an average stocking rate of 12 acres per animal unit month is rotated on 7 pastures, with 3- to 7-week grazing periods, and each pasture deferred for 6 months between each period) or short duration grazing system (a herd multipasture scheme requiring rapid rotation (1 week or less) of livestock through each pasture); (2) four-pasture, deferred rotation (rest rotation) grazing system (for example, three herds rotated on four pastures every 4 months); and (3) continuously grazed system (year-round grazing).

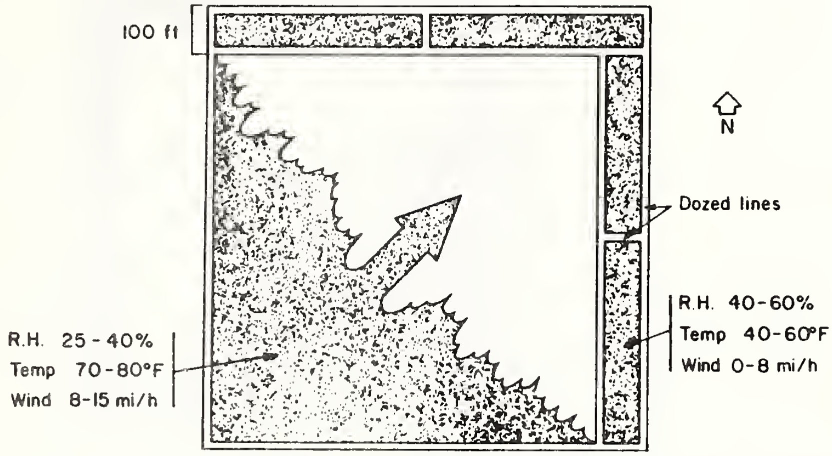
Rotational cattle grazing benefits prairie chickens, sage grouse, blue grouse, and elk (which avoid cattle and use pastures being rested; Knowles and Campbell 1982). Bobwhites and white-tailed deer do best on a high intensity-low frequency system. Bitterbrush is improved for mule deer, because controlled cattle and sheep grazing reduce competing plants. Cattle grazing in late spring and early summer improves winter forage for elk and mule deer. Holechek et al. (1982) and Robinson and Bolen (1984) described in detail wildlife benefits from controlled grazing.



To burn fuels in shortgrass prairie, doze a 3-m (10-ft) line around the entire area to be burned and around the area that you plan to burnout for a fireline, as shown in the figure. Strip-headfire the fireline when relative humidity is 30 to 50 percent and wind speed is less than 16 km/h (10 mi/h). Headfire the remainder of the pasture when relative humidity is 20 to 40 percent, air temperature is 21° to 27°C (70° to 80°F), and wind speed is 13 to 24 km/h (8 to 15 mi/h).

Figure 4-7. Fire plan for shortgrass prairie.

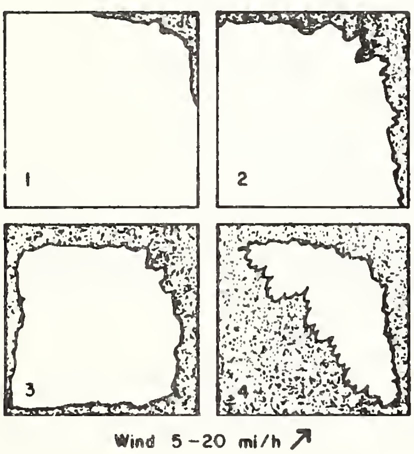
Source: Wright and Bailey 1982



To burn down standing mesquite (sprayed in previous years), doze a 3-m (10-ft) line around the entire area to be burned and within the main area as shown. Strip-headfire the firelines on the downwind sides.

Figure 4-8. Fire plan for tobosagrass-mesquite.

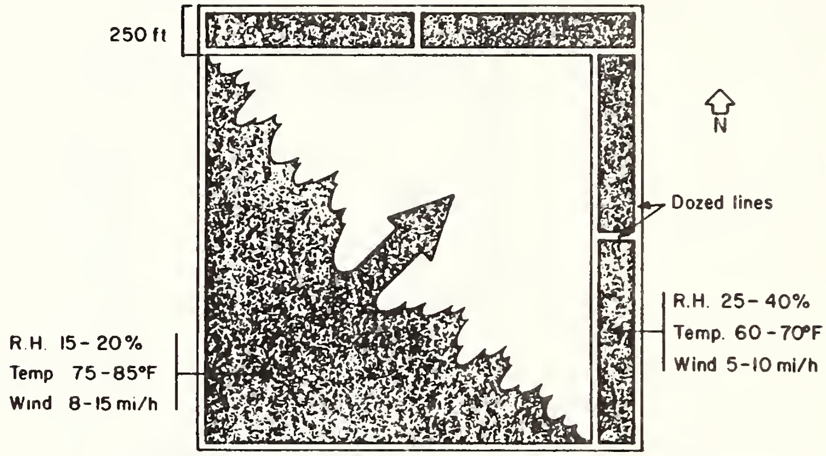
Source: Wright and Bailey 1982



In tallgrass prairie, natural firebreaks, including roads, trails and fenceline cowpaths, are used to the extent possible. In some cases a wetline may be put down with a sprayer where there is no natural break. A backfire is started on the downwind side (1) and lit simultaneously in each direction on the downwind sides (2). After the backfire has burned 15 to 30 m (50 to 100 ft) on the lee sides the remainder of the area is lit (3) and the rest of the area is burned with a headfire (4). Wind speedsmay vary from 8 to 32 km/h (5 to 20 mi/h).

Figure 4-9. Fire plan for tallgrass prairie.

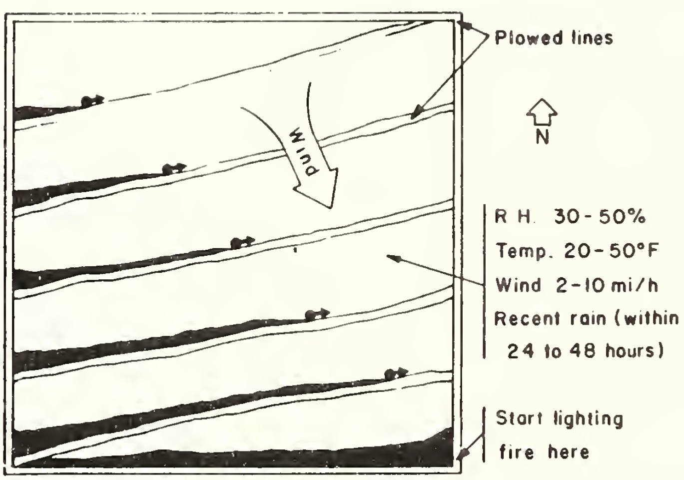
Source: Launchbaugh and Owensby 1978 in Wright and Bailey 1982



Prescribed burning plan for sagebrush-grass communities. Doze a 3 m (10 ft) line around the entire area to be burned and as indicated on the above figure. Strip-headfire the fireline on the lee sides during the morning hours and during early afternoon set the main headfire. Most burns are conducted in the fall, but spring fires are equally satisfactory (maybe better if fine fuel is adequate and the weather is not too cold).

Figure 4-10. Fire plan for sagebrush-grass.

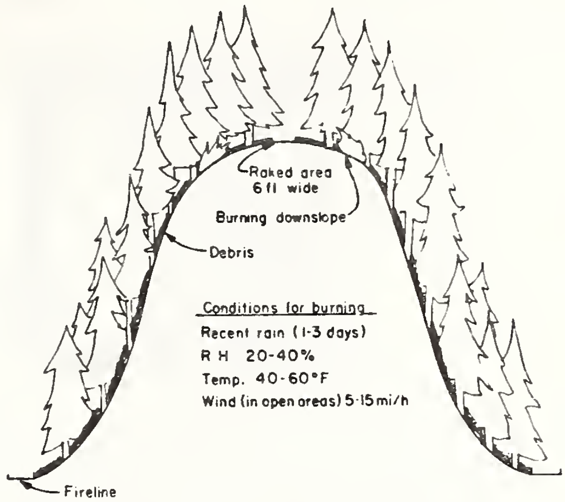
Source: Wright and Bailey 1982



In heavy rough plow a 2-m (6-ft) line around the entire area to be burned (use roads when appropriate) and plow lines at 20-m (66-ft) intervals throughout the unit to be burned.

Figure 4-11. Fire plan for burning rough in Southeast.

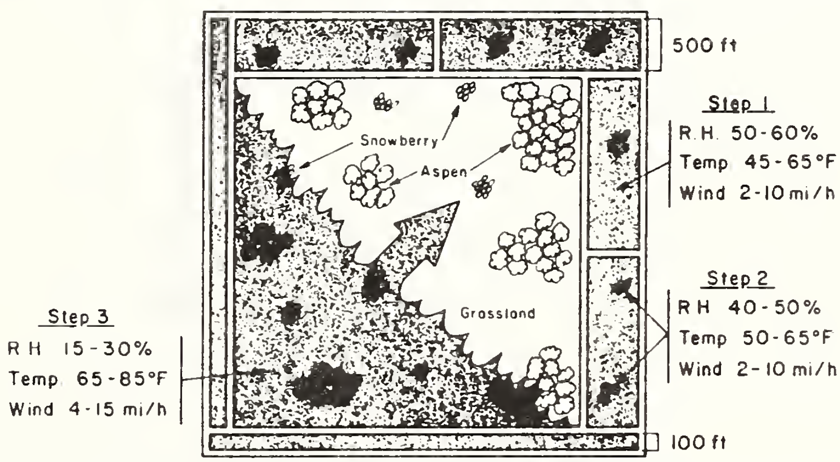
Source: Mobley et al. 1973



Prescribed burns in ponderosa pine. Sometimes the fire is permitted to back down both sides of a ridge simultaneously. A narrow line is cleared at the top of the ridge (raked) and then the fire is lit and allowed to back down the ridge. Recent rains (4 to 5 days before burning) will keep duff moisture high, but needles and small limbs will be dry enough to burn. Occasionally strip-headfires may be used to speed up the burning, especially when conditions become too cool for backfires to move down the ridge.

Figure 4-12. Fire plan for burning understory of ponderosa pine.

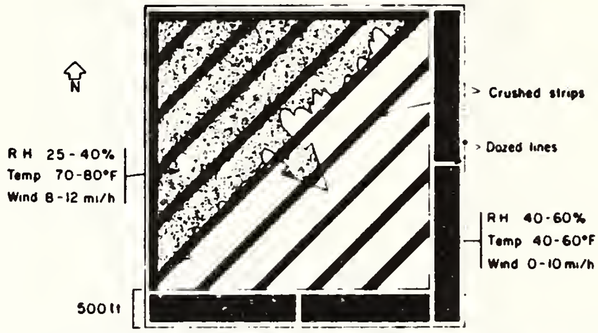
Source: Wright and Bailey 1982



In preparation for a fire in the aspen parkland, doze a 3-m (10-ft) line around the entire area to be burned and between aspen groves as shown in the figure. Burn out the grass in the fireline after it has had one day to dry. Burn out patches of snowberry in fireline after they have had four days to dry. Lastly burn out the main portion of the burn after 14 days of drying weather when relative humidity is below 30%, air temperature is above 18°C (64°F), and wind speed is 13 to 26 km/h (8 to 16 mi/h).

Figure 4-13. Fire plan for burning aspen parkland.

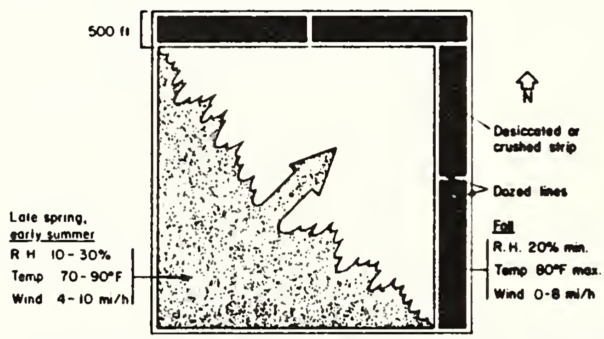
Source: Wright and Bailey 1982



In preparation for a prescribed burn in California chaparral, doze a 3-m (10-ft) line around the entire area to be burned and around the lee fireline as indicated in the figure. Next, crush a 150-m (500-ft) strip on the leeward sides of the area that you plan to burn for the fireline and crush 3-m (10-ft) strips at 20-m (66-ft) intervals throughout the burn. The crushed areas should be prepared in late June or July (2 months before burning). Begin burning firelines with a strip-headfire (Fig. 16.10) in late August or September, preferably during late afternoon or evening when weather is appropriate. Burn in 0.8-km (0.5-mi) strips so that the burning can be stopped when it is too hazardous or will not carry. After the fireline has been prepared, burn the entire area with a headfire under the prescribed conditions indicated on the figure. If chaparral contains 30 percent or more dead material, dozed strips throughout main area are not necessary before lighting headfire.

Figure 4-14. Fire plan for burning California chaparral.

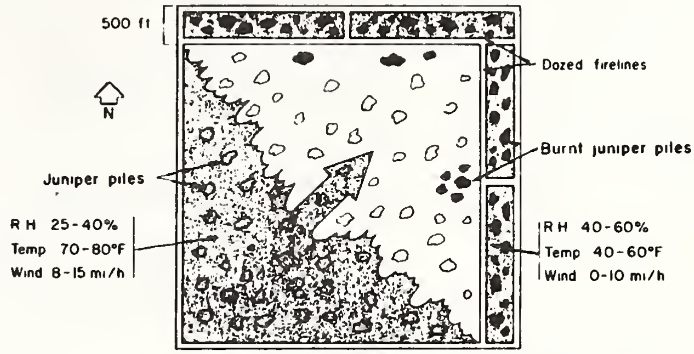
Source: Wright and Bailey 1982



In preparation for a prescribed burn in Arizona chaparral, doze a 3-m (10-ft) line around the entire area to be burned and around the fireline as indicated in the figure. Then either desiccate or crush a 150-m (500-ft) strip on the leeward sides of the area. The desiccated areas should be prepared several weeks before fall burning. If the firelines are to be crushed instead of desiccated this should be done in August. Burn the firelines using the strip-headfire technique in September or October. After the fireline has been prepared, wait until the following May or June to set the main headfire. For further refinements on ROS, see Lindenmuth and Davis (1973) and Davis and Dietrich (1975). The ROS should be less than 20 for green fuel when burning out the fireline and it should be above 20 when setting the main headfire.

Figure 4-15. Fire plan for burning Arizona chaparral.

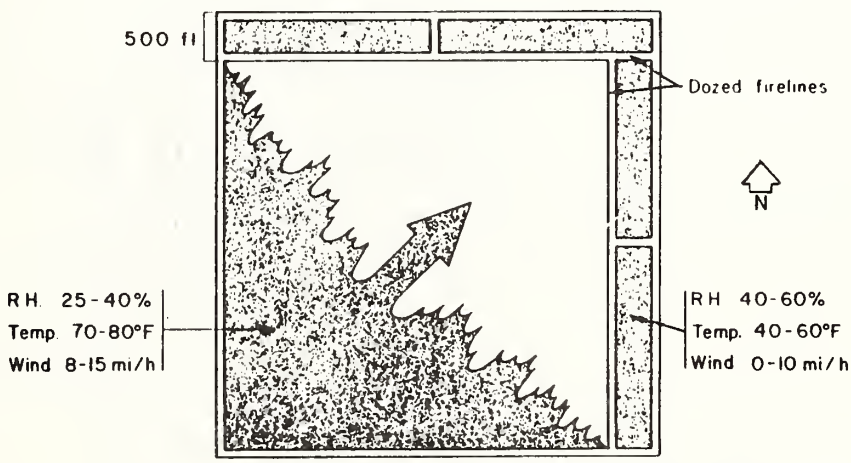
Source: Wright and Bailey 1982



When the grass is green, juniper piles in the 150-m (500-ft) strip (black splotches) on the downwind sides (north and east) are burned with wind velocities less than 16 km/h (10 mi/h) and relative humidity above 45 percent. Eight months later, when grass is dormant, the grass in the 150-m (500-ft) strip is burned (strip-headfire technique) when the wind speed is less than 16 km/h (10 mi/h) and relative humidity is between 40 and 60 percent. Lower relative humidities may be used if the grass fuel is less than 2247 kg/ha (2000 lb/acre). All large concentrations of piles are back-fired on the downwind sides of main area to be burned and then the entire area is burned into the prepared firelines with a wind speed of 13 to 24 km/h (8 to 15 mi/h) and a relative humidity of 25 to 40 percent.

Figure 4-16. Fire plan for dozed juniper (mixed prairie).

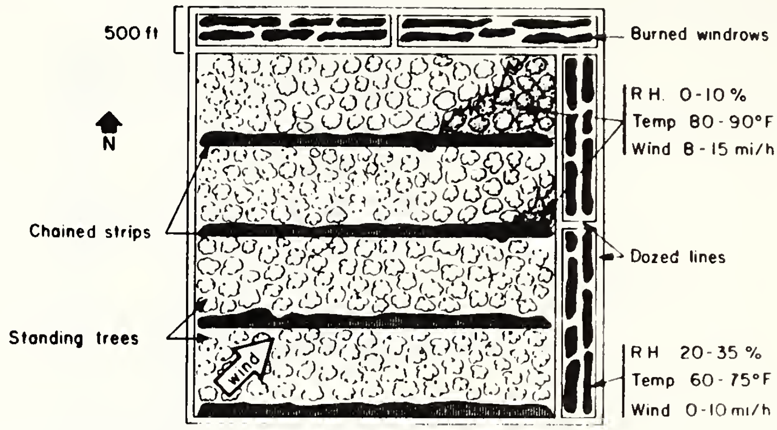
Source: Wright and Bailey 1982



In preparation for a prescribed burn in chained juniper, doze a 3-m (10-ft) line around the entire area to be burned and in interior areas of burn as shown in the figure. Burn out the firelines in January and February. In March, light the main headfire.

Figure 4-17. Fire plan for burning mixtures of pinyon-juniper (mixed prairie).

Source: Wright and Bailey 1982

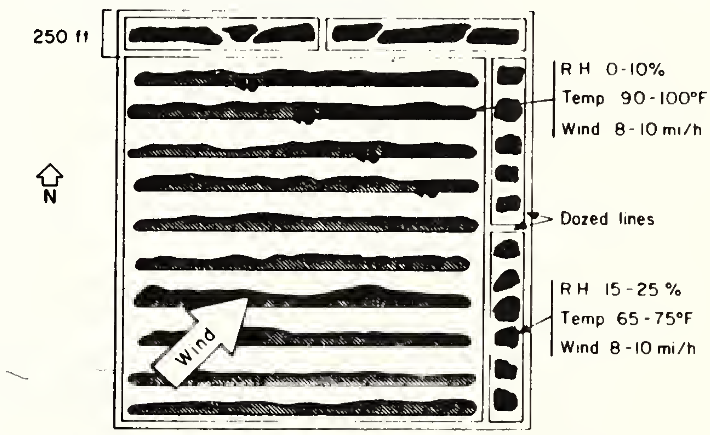


In preparation for a prescribed burn in mixtures of pinyon and juniper, doze a 3-m (10-ft) line around the entire area to be burned and around fireline as indicated in the figure. Chain or crush the strips of juniper in the fireline and at 0.4 km (0.25 mi) intervals throughout the main area to be burned during the winter (60 to 90 days before planning to burn). Burn the fireline in spring or early summer under the conditions listed in the figure. After the fireline has been burned start on the downwind side and light each chained strip. When lighting the strips in the main burn, the combination of air temperature (°F), wind (mi/h), and shrub and tree cover (%) should exceed 125.

Figure 4-18. Fire plan for burning mixtures of pinyon-juniper (no grass understory).

Source: Wright and Bailey 1982

Fire Plan for Chained Juniper
(no grass understory)



In preparation for a prescribed burn in chained juniper, burn out firelines during the morning hours when fire danger is low. Then in the afternoon burn the remaining rows of debris as indicated in the diagram. If grass is present in understory of adjacent fuels, widen firelines on leeward side to 150 m (500 ft.).

Figure 4-19. Fire plan for burning chained juniper (no grass understory).

Source: Wright and Bailey 1982

For pronghorn antelope, the objectives of prescribed grazing are to control high densities of grasses, to increase forbs, or to increase production of preferred browse, such as bitterbrush, which requires two seasons to produce seed (Yoakum 1980). Heavy, early grazing reduces competing bunchgrasses and allows the establishment of bitterbrush and other palatable shrubs (Neal 1982). Cattle should be removed before they damage the bitterbrush (before the red-juice stage of bitterbrush phenology). This treatment can be applied at 15- to 20-year intervals to maintain stands of young, vigorous browse plants.

Native grasses can sustain less grazing than seeded grasses; stocking rates on seeded pastures can be higher. If shrub encouragement is not the goal, 45 percent or more of native forage should be left. Less can be left on seeded pastures. Native rangelands should not be grazed until after June 15 for grasslands and late May for mixed grass prairie (unpublished data, Alberta Agriculture and Canadian Wildlife Service). In general, woodlands should not be grazed. Where wooded areas produce substantial forage, at least 50 percent of the current annual growth of preferred forage species should be left ungrazed. Areas of livestock concentration, with resulting severe grazing and trampling, should not exceed 10 percent of the grazed woodlands (unpublished data, U.S. Soil Conservation Service). These general suggestions will vary with weather, soil, vegetation, and location. There is still substantial disagreement as to the specific effects of different grazing systems on cattle and wildlife (Laycock 1983).

Use of Insects. Insects have been used effectively to kill some undesirable plants, but their use has not been widespread. Vallentine (1971) described their use in controlling certain plants. Before introducing insects, it should be determined whether they are highly destructive to the target species, able to survive in the species' habitat, free of natural parasites, apparently subject to no new parasites in the target species' habitat, and highly specific as to the host plant, so that desirable plants are not harmed.

Rejuvenation

Plants can be rejuvenated to improve growth rates and nutritional value to wildlife by cutting (see Mechanical Methods of Release in this chapter), chemical spraying that burns back the tops but does not kill the shrubs (see Chemical Methods of Release in this chapter), prescribed burning (see Prescribed Burning in this chapter), crushing, pruning, fertilizing, and irrigating.

Crushing and Pruning

Crushing shrubs like bitterbrush with a heavy log covered with rubber tires increases plant growth the second year after treatment. Bitterbrush should be rotocut in early spring with the blade set 18 inches above ground level. Remove shrub competition and prune stems to 4 feet or less to increase leader growth substantially

after two growing seasons (USDA Forest Service 1969c). A commercial orchard pruner, operated by the power take-off of a tractor, may be best for large areas if shrubs are not too dense.

Fertilizing

Fertilizing rights-of-way, trails, and even larger areas of treated or untreated vegetation may be justified to rejuvenate initially (see Fertilizing and Mulching in this chapter). Local wildlife managers and soil conservationists should be consulted to determine the soil's need for lime and fertilizer.

Irrigating

The recent expansion in the use of central pivot irrigation systems and water cannons in agriculture suggests the potential of promoting plant growth for wildlife use. Generally, the expense involved does not justify irrigation, but there may be situations where the monetary value of wildlife does warrant it (U.S. Fish and Wildlife Service and U.S. Bureau of the Census 1982), especially as irrigation systems become more readily available. Irrigation systems are in use on some areas managed specifically for wildlife (see Chapter 3).

Planting

Plantings are expensive, and they should be avoided if natural succession is an acceptable alternative. Working with natural succession is the cheapest and often the best way to achieve diversity. Generally, only lands with fewer than 15 percent desirable perennial species should be considered for seeding. Rutherford and Snyder (1983) described planting techniques.

Selecting Appropriate Plants

Plants for wildlife can be classified as annuals, perennial grasses and forbs, and woody perennials. All three groups can furnish both food and cover, but wildlife uses annuals mainly for food production and perennial grasses and forbs for nesting, summer cover, and food. Most woody plants are used as thermal and escape cover, except for some parts of some species that are heavily browsed (Burger 1973). Martin et al. (1951) listed food plants of value to wildlife. Wenger (1984) listed food plants of value to forest wildlife (Table 4-8).

Annuals are expensive because the yearly replanting and, in most cases, fertilizing, requires time and money. Crop rotation reduces the need for fertilizer. Annuals should be planted for 2 years, and then the area should be seeded to a legume-grass mixture to be plowed under as green manure after one or two growing seasons. Because of varying soil conditions, seed mixtures of adapted species are best for success and diversity. Vegetation can be established by direct seeding or transplanting. Weak-stemmed annuals should be avoided, as they collapse (lodge) under the weight of snow, providing little or no cover or food.

Table 4-8. Food plants of value to forest wildlife.

Regions	Sites	Plants parts predominantly used	Periods of greatest use	Documented animal use
		Key		
NE - Northeast	D - Dry	1 - Leaves	SP - Spring	LC - Large carnivores
NC - Northcentral	M - Medium	2 - Twigs and buds	SU - Summer	SC - Small carnivores
NW - Northwest	W - Wet	3 - Flowers and fruits	F - Fall	LH - Large herbivores
SE - Southeast		4 - Entire	W - Winter	MH - Medium herbivores
SC - Southcentral		5 - Bark		SH - Small herbivores
SW - Southwest				GB - Game birds
IN - Intermountain				SB - Song birds
AR - All regions				

Scientific name	Common name	Region	Site	Plant parts used	Periods of greatest use	Documented animal use
		Trees				
Abies spp. (EV)*	Firs	NE, NC, NW, SW, IN	M, W	3 1	F, W W	SB, LH, SH LH, GB
Acer spp.	Maples	NE, NC, NW, SE, SC, IN	M, W	3 1, 2 5	F SP, W F, W, SP	SP, GB LH, SH MH
Betula spp.	Birches	SE, SC, NW, NC, NE, IN	D, M, W	1, 2 3 5	F, W F, W F, W, SP	LH, GB GB, SB MH
Carpinus caroliniana	American hornbeam, blue-beech	NE, SE, SC	M, W	5	F, W, SP	MH
Carya spp.	Hickory, pecan	NE, NC, SE, SC	M, W	2, 3	F, W	LH, SH, GB, SB
Cornus spp.	Dogwoods	AR	M, W	1, 2, 3 3	F, W F, SU	LH GB, SB, LC
Diospyros virginiana	Common persimmon	SE, SC	D, M	3	F	LH, LC, SH, SC, SB, GB
Fagus grandifolia	American beech	NE, NC, SE, SC	M	2, 5 1, 2, 5	F, W SP, F, W	GB, MH LH, MH
Fraxinus spp.	Ash	AR	M, W	3	F	SH, GB, SB
Gleditsia triacanthos	Honeylocust	SE	M	3	F, W	LH, SH, GB
Ilex opaca (EV)	American holly	NE, NC, SE, SC	M, D	3 1	F, W W	LH, LC, SB, SB LH
Juniperus spp. (EV)	Cedars (Red)	AR	D, M	3	S, F, W	LH, SC, SH, GB
Larix spp.	Larch, tamarack	NE, NC, NW	W	1, 3	F	GB, SB
Libocedrus decurrens (EV)	Incense-cedar	N, W, SW	M, W	1	W	LH
Liriodendron tulipifera	Yellow-poplar, tulip tree	NE, NC, SE, SC	M M	1, 2, 3, 5	F, W, SP	LH, SB, MH
Magnolia spp.	Magnolia, cucumbertree	SE	M	1, 2	SP, W	LH
Magnolia virginiana (EV)	Sweetbay	SE	W	1	F, W	LH
Melia azedarach	Chinaberry	SE, SC	M	3	F, W	LH
Morus rubra	Red mulberry	NE, NC, SE, SL, SW	M	1, 2, 3	SP, S	LH, GB, SB
Nyssa spp.	Blackgum, black tupelo, water tupelo	NE, SE, SC	W, M	1, 2 5, 3	SP, F, W F	LH, MH LH, LC, SC, GB
Oxydendron arboreum	Sourwood	SE	M	1, 2 1	SP, W F, W	LH LH, LC
Persea borbonia (EV)	Red bay	SE	W	3	F, W	LH
Picea spp. (EV)	Spruce	NE, NW, IN, NC	D, M, W	1, 2, 5 1	W W	MH, LH LH
Pinus spp. (EV)	Pines	AR	D, M, W	1, 2, 5 3	F, W, SP F, W	MH, LH GB, SB, SH
Populus spp.	Bigtooth aspen, quaking aspen, cottonwood	AR	MW	1, 2, 3 5	F, W, SP, SU	GB, LH, SH, MH

Table 4-8 (continued). Food plants of value to forest wildlife.

Scientific name	Common name	Region	Site	Plant parts used	Periods of greatest use	Documented animal use
Wyethia spp.	Mulesears	SW	D, M	1	SU	LH, SB, SH, GB
		Grasses				
Agropyron spp.	Wheatgrass	IN, NW, SW	D	4	SU	LH
Arundinaria giganica'	Giant cane	SE	W	4	F, W, SP	LH
Bromus spp.	Bromegrass	SW, IN, NC	D, W		W, F, SP	LH, GB, SH, SB
Distichlis spicata	Alkaligrass	SW, NW, NC, IN	M, D, W	4	SU, F W	SH LH
Elymus spp.	Wildrye	AR	D, M	4	SP, SU, F, W	LH
Festuca spp.	Fescue	AR	D, M	4	SP, SU, F, W	LH, SH, SB
Koeleria cristata	Prairie junegrass	NW	D	4	SU	LH
Leersia spp.	Cutgrass	AR	W	1, 3	SU	MH
Melica spp.	Melic	SW, IN, NW	D	3	SU	SB, GB, SH
Muhlenbergia cuspidata	Stoneyhills muhly	NW	D	4 3	 SW	LH SB, GB, SH
Panicum spp.	Panicgrass	SE, SC	M, W	1, 2 3	W SU	LH GB, SB
Paspalum spp.	Paspalums	SE, SC, NE	W	1, 3	SP, SU	LH, GB, SB
Poa spp.	Bluegrass	NW	M	4	W	LH
		NE, NE, NC, IN			F	SH, SB, GB, LH
Sacciolepis triata	American cupscale	SE	W	4	W	LH
Setaria spp.	Bristle grass	AR	M	1, 2, 3	F	GB, SB
Sitanion spp.	Squirreltail	SW, SC, NC	D		F, SU	
Stipa spp.	Needlegrass	NW	D	4 3	 F	LH SB, GB, SH
		Grass-like				
Carex spp.	Sedges	AR	D, M, W	1, 3 4	 SU, SP	MH LH, LC
Eleocharis spp.	Spikesedge	AR	W	1, 3	SU	MH
Juncus spp.	Rush	AR	W, M	4	SP, SU, W	LH, SH
Scirpus americanus	Bulrush	SW	W	4 3	W W	LH SB
		Other				
Equisetum spp.	Horsetail	NE, NC, NW	W	1	SP, SU, F, W	MH, LC
Fungi	Mushrooms	AR	M, W	4	SP, SU, F, W	LH, SH, LC, SC, GB, SB
Osneacae	Lichens	SW, NW	D, M, W	4	F, W	LH, SH
Phoradendron spp.	Mistletoes	SE, SW, SC, NW, IN	M, D	3, 4	SP, S, F, W	LH, SB
Monotropa spp.	Indianpipe	SE, NE, NC, NW, IN	M	4	F	LH

*EV = Evergreen

All other species are deciduous or have species that are both evergree or deciduous

Source: Wenger 1984

Table 4-8 (continued). Food plants of value to forest wildlife.

Scientific name	Common name	Region	Site	parts used	Periods of greatest use	Documented animal use
Sambucus spp.	Elderberries	AR	M, W	1, 2, 3	SP, F, W, SU	LH
				3	SU	GB, SB, LC, SC, SH
				5	W	LH, SH
Serenoa repens (EV)	Saw-palmetto	SE, SC	D, M	3	F, W	LC, LH
Symphoricarpos spp.	Coralberry, snowberry, wolfberry	NE, NC, NW, SW, IN	M, D	1, 2, 3	SP, F, W, SU	LH
				3	F	GB, SB, SH
Vaccinium spp.	Blueberries, deerberries	AR	D, M, W	1, 2, 3	SP, F, W, SU	LH
				3	SU, F	LC, SC, SB, GB
Virburnum spp.	Rusty blackhaw, virburnum, possumhaw, arrowwood, nannyberry, witherod	AR	M, W	1, 2	W, SP	LH
				3	F, W	GB, SB, SH
				5	W, SP	SH
		Vines				
Berchemia scandens	Alabama supplejack	SC, SE	M	1, 2, 3	SU	LH, GB, SB
Gelsemium sempervirens (EV)	Yellow jessamine	SE, SC	M	1, 2	F, W	LH
Lonicera spp. (EV)	Honeysuckles	AR	D, M, W	1, 2, 3	F, W, SP, SU	LH, SH, SB
Rhus spp.	Poison ivy, poison oak	NE, SE, SC, NW, SW	M, W	1, 2, 3	F, W, SU	GB, SB, LH, SH
Smilax spp. (EV)	Greenbriers	NE, SE, SC, SW	D, M, W	1, 2, 3	F, W, SP	LH
				3	F	GB, SB
Vitis spp.	Grapes	AR	D, W, M	1, 2, 3	SP, SU	LH
				3	F	GB, SB, SH, LC, SC
		Forbs				
Achillea spp.	Yarrow	SW	D, M, W	4	SP, SU, F, W	LH
Agoseris spp.	Agoseris	NW, NC	D, W	4	F	LH
Ambrosia spp.	Ragweed	SE, SW, IN	M	4	SP, SU, F	LH, SH
				3	SU, F	GB, SB
Anaphalis spp.	Pearly everlasting	NE, NC, NW, IN	D, M	4	SU, F	LH
Antennaria spp.	Pussytoes, everlasting, lady's tobacco	AR	M, D	3, 4	SP, SU, F	LH
Aphanostephus spp.		SW	D	4	SP	LH
Arnica spp.	Arnica	SW		3		SB, GB, SH
Aster spp.	Asters	NE, NC, SE, SC, IN	D, W, M	1, 2, 3, 4	SP, SU, F	LH, SH, SB, GB
Balsamorhiza spp.	Balsamroot	IN, SW, NW	D, M	1	SU	LH
Brodiaea spp.	Brodiaea	NW, SW	D, M, W	4	SP, SU, W	LH, SH
Callirhoe involucrata	Poppymallow	SW	D	4	SP	LH
Calyptridium umbellatum	Pussypaws	NW, SW	D	4	SU	LH, SH, SB
Cassia nictitans	Partridgepea	SE	M, D	3	F	GB
Centella repanda	Centella	SE	M, W	4	SP, SU, F, W	LH, GB
Cirsium spp.	Thistle	SW	D, M	3	SU	SB, SH, GB, LH
Cornus canadensis	Dwarf cornell, bunchberry	NE, NC	M	3	F	GB
Croton spp.	Croton	AR	D	3	SU, F	GB, SB, SH
Descuraina pinnata	Pinnate tansy mustard	AR	D, M	4	SP, SU, F	LH
Desmanthus spp.	Bundleflower	SE, SW	D, M	4	SP, SU, F	LH
Desmodium spp.	Beggarweed, tick-trefoil	SE	D, M	3	F	GB
Epigaea repens (EV)	Trailing-arbutus, mayflower	NE, SE	M	4	F, W	LH, GB
Epilobium spp.	Willowweed, fireweed	AR	D, M, W	4	SP, SU, F	LH, SH, GB, SB
Eremocarpus setigerus	Turkey mullein	SW		3	F, W	GB
Erigeron spp.	Fleabane	SW		3		SB, SH, GB
Eriogonum spp.	Dog-tongue, wild buckwheat	NE, SE, IN, SW	M, W	1, 2, 3	F, SU, W	GB, LH, SB, SH
Eriophyllum spp.	Wooly sunflower	SW		3		SB, SH, GB

Source: Wenger 1984

Table 4-8 (continued). Food plants of value to forest wildlife.

Scientific name	Common name	Region	Site	parts used	Periods of greatest use	Documented animal use
Erodium spp.	Filaree, heronbill	NW, SW, IN	D, M	4	SP, SU	LH, SH
Eupatorium rugosom	White snakeroot	SE	M	4	SP, SU, F	LH
Fragaria spp.	Strawberry	NE, NC, NW, SE, IN	D, M, W	4	SP, SU, F	LH, GB, MH, SB, SH
Galax aphylla (EV)	Galax	SE	M	4	F, W	LH
Galyophytum spp.	Groundsmoke	SW	D, M	4	SU	LH, SB
Gaultheria spp.	Teaberry, wintergreen, checkerberry	NE, NW, NC, SE	M	4	F, W	LH, GB, SH
Gayophytum spp.	Groundsmoke	SW	D, M, W	4	SP, SW, F, W	LH
Geum spp.	Avens	SE, NE, IN	M, W	1, 3	F, W	GB, SB, SH, LH
Heuchera villosa	Alumroot	SE	M, W	1	F, W	GB
Hieracium pilosella	Mousear, hawkweed	SE	M	4	SP, SU, F	LH
Impatiens carpensis	Jewelweed	NC	W	1	SU	LH
Lactuca spp.	Lettuce	AR	D, M	1, 2, 3,	SP, SU, F	LH, GB
Lathyrus spp.	Peavine	NC, NW	M	1	SU, F, SP	LH, LC
Lespedeza striata	Common lespedeza	SE	M	3	F	GB, SB
Lotus spp.	Deervetch	AR	D, M, W	3	SP, SU, F, W	LH, GB
Ludwigia spp.	Ludwigia	SE	W	4	SP, SU, F, W	LH
Lupinus spp.	Lupine	AR	D, M, W	3	SU, F	LH, GB
				4	SP, SU, F, W	LH
Medicago spp.	Medic	AR	D, M	4	SP, SU, F, W	LH, GB
Melilotus spp.	Sweetclover	SW	D, M, W	3, 4	SP, SU, F, W	LH, GB
Menispermum canadense	Moonseed	NW	M, W	1	F	LH
Mitchella repens	Partridgeberry	NE, NC, SE	M	4	F, W	LH, GB, SC
Nymphaea odorata	Waterlily	NE, SE	W	4	SP, SU, F, W	LH
Osmunda regalis	Royalfern	NE, SE	W	4	F, W	LH
Oxalis spp.	Woodsorrel	NE, NC, NW	M	4	F	LH, SB
Parthenium spp.	Parthenium	SW	D	4	SP	LH
Penstemon	Penstemon	NW, IN, SW	D, M, W		SP, SU, W, F	SH, SB, GB, LH
Physalis spp.	Ground cherry	SW	D	4	SP	LH
		NC		1	SU	LH
Plantago spp.	Plantain	SE	M	3, 4	W	LH, SB
Plagiobothrys spp.	Popcornflower	SW	D, M	4	W, SP	LH, SH, GB
				3	SU	LH
Polygonum	Smartweed, knotweed, fringed bindweed	AR	W, M	3	F, W	GB, SB
Polystichum spp.	Christmasfern, western sword fern	NE, SE, NC, NW	M, D	4	F, W	LH, GB, MH
Potentilla spp	Cinquefoil	NE, SE, NC, SC SW, NW, IN	M, W	4	SP, SU, F	LH, GB, SB
				1	SP	LC
Ranunculus spp.	Buttercup	AR	M, W	4	F	GB
				1	SP	LC
Rumex acetosella	Sheepsorrel	SE	M, W	1	F, W	GB
		SW	M, W	4	W, SP, SU	LH, SH
Solidago spp.	Goldenrod	NE, SE, SC, IN	D, M, W	1, 2, 3, 4	SP, SU, F	LH, SH, SB, GB
Taraxacum vulgare	Dandelion	AR	D, M, W	4	SP, SU, F	MH, LC
				1, 2, 3	F, SP, SU	GB, SB, SH, LH
Trifolium spp.	Clovers	NE, NC, NW, SE	M, W	4	SP, SU, F	GB, LH, MH, LC
			SW, IN	1, 3	W	SH
Trilisa odoratissima	Vanilla trilisa, deer's tongue	SE	M, W	4	F, W	LH
Vicia spp.	Vetch	NC	M	1	SU, F, SP	LH, LC
Viola spp.	Violet	NE, NC, NW, SE, SC, IN	M, W	4	SP, SU, F	GB, LH, SH, SB

Source: Wenger 1984

Table 4-8 (continued). Food plants of value to forest wildlife.

Scientific name	Common name	Region	Site	parts used	Periods of greatest use	Documented animal use
Prunus spp.	Cherries, plums	AR	D, M, W	2 3 5	W F F, W, SP	GB, LH, MH LH, SH, LC, SC, GB, MH
Pseudotsuga menziesii (EV)	Douglas-fir	NW, IN	M	1 3 5	F, W F, W F, W, SP	LH, GB GB MH
Quercus spp.	Oaks, oaks (EV)	AR	D, M, W	1, 2, 3, 5	F	LH, SH, LC, GB, SB, LH,
		SE, SC, SW	D, M	1, 2, 3	F, W, SP	SH, LC, GB, SB
Sabal palmetto (EV)	Cabbage palmetto	SE, SC	M, W	3	F, W	LC, SC, LH, SH, GB, SB
Salix spp	Willow	AR	M, W	1, 2	SU, F	LH, SB
Sassafras albidum	Sassafras	NE, NC, SE, SC	D, M	1, 2, 3 3	SP, SU, F, W F	LH SH, SB, GB, LC, SC
Taxodium spp.	Cypress	SE, SC	W	3	F, W	GB
Thuja spp. (EV)	Cedars (white)	NE, NC	M, W	1 1	W W	LH LH
Tsuga canadensis (EV)	Eastern hemlock	NE, NC	M	3 5	W W	SB MH
Ulmus spp.	Elms	AR	D, M	5	F, W, SP	MH
		Shrubs				
Acacia berlandieri	Gaujillo acacia	SW	D	1	F, W, SP	LH, GB
Adenostoma fasciculatum	Chamise	NW, SW, IN	D	1, 2, 3		LH, SH, SB
Alnus spp.	Alders	AR	W	1, 5 3 2, 5	SP, SU F, W W	MH GB, SB, LH MH, LH, SH
Amelanchier spp.	Serviceberry	NE, SE, SC, SW, NC, IN	D, M, W	1, 2, 3, 5	F, W, SP	LH, GB, SB, MH, LC
Arctostaphylos spp. (EV)	Bearberry, manzanita	SW, NW, IN	D	1, 2, 3	W, SP, SU, F	LH, SH, LC, SC, GB, SB
Aronia spp.	Chokeberry	NE, NC, SE, SC	D, M	1, 2 3	W F	LH GB, SB
Artemesia spp. (EV)	Sagebrush	SW, NW, IN	D, M	1, 2, 3	W	LH, SH, SB, GB
Berberis aquifolium (EV)	Oregon-grape	NW, SW, IN	D, M	1 3	W F	LH GB, LC
Bumelia spp.	Bumelia	SW	D, M	1, 2	SP, F, W	LH
Calliandra eriophylla	Calliandra, false-mesquite	SW	D	1	W	LH
Ceanothus spp.	Jerseytea, deerbrush, buckbrush (EV), whitethorn (EV)	AR	D, M	1, 2, 3	F, W, SP, SU	LH, SH, SB
Celtis pallida	Spiny hackberry	SW, SC, NW, IN, NC	D, M	1, 3 3	F, W F	LH SB, GB, SH, SC
Cephalanthus occidentalis	Buttonbrush	SW, SE, NE, SC	W	1, 2, 5	SU	MH, SB
Cercocarpus spp.	Curlleaf, mountain-mohogany (EV), true mountain-mahogany	SW, NW IN, SW	D, M	1 3	W, SP	LH SB, SH, GB
Chamaebatia foliolosa	Bearmat, misery mountain	SW, NW	D, M	1 3	 W, SP, SU	LH SB, SH, GB
Chrysothammus spp.	Rabbitbrush	NW, SW, IN	D, M	1, 2, 3	SP, SU, F, W	LH, SH, SB, GB
Condalia spp.	Condalia	SW	D, M	1, 2	SP	LH
Corylus spp.	Hazelnuts	NE, NW, SE, SW	D, M	2, 3 5	F, W, SP F, W, SP	GB, LC, LH, MH, SH
Cowania mexicana	Cliffrose	SW, IN	D	1, 2, 3, 4	F, W, SP	GB, SB

Source: Wenger 1984

Table 4-8 (continued). Food plants of value to forest wildlife.

Scientific name	Common name	Region	Site	Parts used	Periods of greatest use	Documented animal use
Crataegus spp	Hawthorns	AR	D, M	1, 2, 3	F	GB
Cyrilla racemiflora	Swamp cyrilla, leatherwood	SE, SC	W	1, 2	F, W	LH
Dalea spp.	Dalea	SW	D	1, 2	SP, F, W	LH
Diervilla lonicera	Bush honeysuckle	NC	D, M	1, 2	SP, SU, F	LH
Euonymus spp.	Strawberry bush	NE, SE, NC, SC	M	1, 2	SP, F, W	LH
Eurotia lanata	Winterfat	SW, NW, NC, IN	M	1, 2, 3	F, W, SP	LH, SH, SB, GB
Fallugia paradoxa	Apacheplume	SW, IN	M, D	1, 2, 3	F, W, SP	
Garrya spp.	Silktassel	NW, SW, IN	M	1, 2	F, W	LH
Gaylussacia spp.	Huckleberries	AR	D, M, W	1, 2, 3 3	SP, SU, F, W SU, F	LH GB, SB, LC, SC
Hamamelis virginiana	Witch-hazel	NE, SE, SC, SW	M, W	2, 3	F, W	GB
Heteromeles arbutifolia (EV)	Toyon, christmas-berry	SW SW	D	5 1, 3	F, W, SP F, W	MH LH, GB, SB
Ilex spp. (EV)	Hollies,	SE, SC, NE, NC	M, W	1, 3	F, W	LH, SH, LC, GB, SB
	dahoon holly,	SE, SC	M, W	1, 3	F, W	LH, GB, SB
	large gallberry,	SE, SC	M	1, 3	F, W	LH, GB, SB
	inkberry,	NE, SE, SC	M	1, 3	F, W	LH, GB, SB
	winterberry,	NE, NC, SE	M	1, 2, 3	F, W	LH, LC, GB, SB
	yaupon	SE, SC	W, M	1	F, W	LH, SH
Juniperus spp. (EV)	Common juniper, ground juniper,	NE, NC, NW, SW	D, M	1	W	LH
	California juniper	IN		3	F, W	GB, SB
Kalmia spp. (EV)	Mt. laurel, lambkill	NE, NC, SE, SC	M, W	1, 2	F, W	LH, SH, SB
Lycium berlandieri	Wolfberry	SW, IN, NW	D, M	1, 2, 3	SP	LH
Menziesia pilosa	Alleghany menziesia	NE, SE	M, W	2	W	GB
Myrica spp.	Waxmyrtle, bayberry	NE, SE, SC	M, W	3	F, W, SP, SU	LH, SB, GB, SH
Opuntia spp. (EV)	Cactus, pricklypear, cholla	SE, SC, SW, IN	D	3, 4	F, W	LH, SB, SH
Porliera angustifolia	Texas porlieria	SW	D, M	1, 2	SP	LH
Potentilla fruiticosa (EV)	Shrubby cinquefoil	NE, NC, NW, SW, IN	D, M	1, 2		LH
Prosopis spp.	Mesquite	SW, IN	D	1, 3	F, W	LH
Prunus spp.	Stonefruits	AR	D, M	1, 2, 3	SP, SU, F	LH, SH, SB, GB
Psilostrophe spp.	Paperflower	SW	D	1	SP	LH
Purshia tridentata	Bitterbrush	SW, NW, IN	D, M	1, 2, 3	W, SP, SU, F	LH, SH, SB, GB
Quercus spp. (EV)	Oaks (scrub, ground)	SE, SC, SW	M, D	1, 2, 3	F, W, SP	LH, LC, GB, SH, SB
Rhamnus spp. (EV)	Buckthorn	SW	D, M	1, 2, 3	W, SP, SU, F	LH, SH, LC
Rhododendron spp. (EV)	Rosebay, azalea	NE, NC, SE, SC	M, W	1, 2	F, W	LH, GB
Rhus spp.	Sumac	AR	M, D	2 3	F, W F	MH LH, SB, GB, MH
Ribes spp.	Gooseberry	SW	D, M	1, 2, 3 1, 2, 3, 4	SP, SU, F SP, F, W	LH, SH, SB, GB, LC, SC LH
Rosa spp.	Roses	AR	D, M, W	3 2 4	F, SU W F, SU	GB, SB, SH, LC, SC MH, LH MH
Rubus spp.	Blackberries, raspberries, dewberries	AR	D, M, W	1, 2, 3 2 4	SP, SU W SU, F	LH, SH, LC, SC, SB, GB MH, LH
Sabal spp (EV)	Scrub palmetto	SE, SC	D, M	3	F, W	LC, LH
Salix spp	Willows	AR	M, W	1, 5 1, 2 5	SP, SU SP, W, F, SU F, W, SP	MH LH, SB, MH, SH MH, SH

Source: Wenger 1984

Site Factors

Site factors (soil, slope, shade, and drainage) and climate determine which plants will thrive. The most important elements of successful plantings are site selection, site preparation, time of planting, planting depth, and soil moisture. Competition for nutrients and especially moisture must be reduced by scalping, if necessary, with spot planting. For large plantings, the site should be prepared by standard farming methods. The objective is to plant in a clean, firm seedbed. This may involve plowing or disking and the drilling of seed. With zero tillage or stubble seeding, crops are seeded directly into unprepared soil or stubble by cutting a narrow slot deep enough to cover the seed with moist soil. Weeds can be controlled with herbicides. Benefits of zero tillage include more stable soil moisture, less soil erosion, less surface water drainage and salinity problems, more stable soil temperatures to speed up germination, time savings, and more waste grain left for wildlife as food and cover over winter. The U.S. Soil Conservation Service lists plant species and propagation characteristics for many States, the USDA Forest Service lists them for regions of the United States, and County agents and State wildlife agencies can provide local information. Useful publications are cited by Yoakum et al. (1980) and reported in Monsen and Shaw (1983).

Seed Collection

Seeds of native plants not available commercially will have to be collected (Larson 1980), which requires knowledge of time of ripeness and proper handling, storing, and treatment before planting (Mirov and Kraebel 1939, U.S. Forest Service 1969b, 1974a).

Ground Preparation

The aims of ground preparation are to reduce competition and provide enough moisture and nutrients. Equipment used most includes moldboard plows (which turn over heavy soils or sod), offset disks (which chop and turn over trash), brushland plows for rough plowing on rocky or uneven terrain, and contour (Holt) trenchers (which can operate on slopes up to 45 percent to reduce runoff, conserve moisture, and prevent erosion). Vallentine (1971) compared other types of equipment (Table 4-9).

Fertilizing and Mulching

Wildlife is attracted to fertilized areas (Carpenter and Williams 1972). To determine the need for fertilizing, the soil should be tested through the County agent. Lime may be added to reduce acidity. Mulches often are spread over seeded areas to shelter new seedlings, retain moisture, and reduce erosion. They are especially useful on arid sites or steep slopes.

Table 4-9. Comparison of mechanical equipment used in seedbed preparation on rangeland.

Equipment	Areas suitable	Disadvantages
Pipe harrow	Adapted to rocky and steep sites where more effective machinery is not adapted. Also, scarifies soil sufficient for covering broadcasted seed on burns, abandoned roads, or excavation scars.	Low kill of large shrubs, sprouting or willowy plants, and most herbaceous plants; may not clean itself; brings many rocks to the surface; and must be disassembled before transporting.
Moldboard plow	Widely used on cultivated soils that are rock free, dense, and tight, but seldom on range.	Slow; high power per width of cut; high cost; ineffective on hard, sticky or rocky soil; picks up roots and trash; tolerates only very small brush.
Pitting	Many types available, including pitting disk plow with cut-away or eccentric disks. Adapted to medium-heavy textured soils on deteriorated range, go-back lands, and areas of low precipitation. Pits trap snow and water and protect young seedlings.	Does not reduce dense, perennial sod, rhizomatous plants, or brush sufficiently for good seedling establishment. Must often be preceded by plowing.
Railing	Adaptation very limited for seedbed preparation.	Ineffective on herbaceous plants and limber or sprouting shrub species; insufficient soil scarification for adequate coverage of previously broadcasted seed except on sandy soil.
Chaining and cabling	Adapted to large, nonsprouting brush such as juniper and mature big sagebrush and on areas too rocky, rough, or steep for other equipment. Low cost per acre. Used on large acreages where total destruction of understory vegetation is undesirable.	Low kill of sprouting brush and understory species. Seeding limited to broadcasting prior to final chaining. Special equipment needed for loading and transporting chain.
Bulldozing	Generally unadapted as sole treatment in seedbed preparation except where used for blading into windrows (Figure 80). Often preceded by chaining or followed by other treatments such as chaining or plowing for final seedbed preparation.	Leaves seedbed very rough; costly in complete land treatment; maximum soil disturbance; generally requires additional treatments such as piling brush, plowing, or subsequent chaining of cleared areas.
Standard disk plow	Adapted to deep soils free of rocks. Will penetrate hard soils and withstand sticky soils.	High cost per acre; slow; loosens soil too much; high breakage on range; narrow cut and high draft.
Wheatland plow	Adapted to gentle terrain with nearly rock-free, moderately soft soil; frequently used on land previously cultivated and for light tillage in second time over. Commercially available. Plowing depths readily adjusted on even terrain.	High breakage on rough, rocky, brushy sites; often plows too shallow, second time over generally required.
Brushland plow	Adapted to brush up to 2" in diameter, hard soil, uneven terrain, rocks, and stumps with low breakage. More effective than wheatland plow on uneven, rocky sites. High kill with single treatment.	High initial cost; difficult to transport; heavy draft; may leave seedbed too soft; not commercially available.
Offset disk	Heavy models adapted to most areas not too rocky. Commercially available. Adapted to hard, dry, heavy soils. Cutaway disks do a better job of mulching the vegetation. High kill with once-over treatment.	Difficult to regulate plowing depth, particularly on sandy or loose soils; difficult to transport; seedbeds often too loose without packing by other equipment; leaves dead furrows that may induce water erosion; drafty.
Root plow	Adapted to deep, rock-free soils with brush too large or too dense for other equipment.	Not adapted to shallow, rocky, rough, steep, or muddy sites. High initial cost and drafty. Rhizomes of sprouting species must be worked to the surface to prevent sprouting. Seedbed generally too soft for successful seeding until after loose, open soil has been compacted.

Source: Vallentine 1971

Nitrogen fertilizers increase protein and dry-matter production in forbs and shrubs. Sulfur and phosphorous fertilizers increase legumes and other plants with nitrogen-fixing nodules on roots. In some regions, grasses need large amounts of nitrogen fertilizer for best growth. It should be applied during or just before periods of active growth, as one application is effective for only 1 to 3 months. Add fertilizer in early spring and summer for warm-season species, and at the time of seeding in fall and again in mid-winter for cool-season annuals. Care must be exercised to prevent nitrate contamination of surface and groundwater by overfertilizing, especially on porous soil with high leaching potential.

Fertilizers can be applied over large areas by fixed-wing aircraft and helicopter spreaders (Larson 1980). Ground application involves truck-mounted or towed spreaders. Power mulchers blow dry fiber mulch, mostly hay and straw, over inaccessible slopes. The Estes blower spreader is a blower/impactor attachment for the hopper of a large, truck-mounted rotary spreader, which blows lime, fertilizer, shredded bark, wood chips, or seed up to 125 feet horizontally or 75 feet up or down a 60° slope. Vallentine (1971) describes types of fertilizer, uses, and rates of application.

Final Seedbed Preparation

To have a clean seedbed for germination and establishment, undesirable competing vegetation should be eliminated and the soil pulverized. This is best done by disking as often as needed. Disk harrows are used for secondary tillage and incorporating mulches and other amendments into the soil. They can also be used for primary tillage. Other recommended equipment includes spring tooth harrows and field cultivators for moderately rocky and trashy areas not suitable for disking, and the auto tire compaction unit for firming seedbeds and covering seed on rough terrain. The klodbuster prepares steep slopes for seeding, without putting a prime mover on the slopes. The lead chain is attached to a tractor or truck operating on a road or bench above the slope, and may be 160 feet long to the slope wheel. The klodbuster is ineffective on slopes under 20 percent, at speeds less than 5 mph, or on slopes with stumps and large rocks.

Seeding

Seeding summer grasses and legumes should be timed to the rainfall pattern of the area. When winter moisture is sufficient or greater than summer moisture, seeding should occur in late winter or early spring. Seeding should not be substituted for proper management. Grazing should be deferred until the plants are well established. Vallentine (1971) lists seeding rates, characteristics, and regional adaptability of 80 forage plants commonly seeded on range and other perennial pasture, and describes limited tilling procedures.

Like fertilizer and chemicals, seed can be distributed over large, irregular, or steep areas with fixed-wing aircraft or helicopter spreaders (Larson 1980). For ground application, planting the seed is better than broadcasting it, which requires 50 to 55 percent more seed for a comparable stand. Poorly prepared seedbeds require more seed. After broadcasting, many species of seed require covering by harrowing, chaining, cabling, and so forth, but some can be broadcast into ashes after prescribed burning (Crawford and Bjugstad 1967). Equipment used for seeding was described by the Range Seeding Equipment Committee (1970) and Larson (1980), with the most common described briefly here.

Following are implements for seeding:

Deep-furrow Drill. The deep-furrow drill creates a furrow 2 to 3 inches deep, spaced at 12-inch intervals or wider. The 28-inch spacing is considered the most practical for planting browse. Spaces can be installed readily in the seedbox to allow seeding of different species in alternate rows. The drill is mounted on rubber tires, can be pulled by a light tractor or jeep, and is designed for rough rangelands. It can be hauled on a 1.5-ton truck. On level land, the drill seeds well and leaves a good seedbed for emergence. Its limited maneuverability renders it impractical for seeding small openings.

Hansen Browse Seeder. The Hansen browse seeder can be equipped with 16-inch or 32-inch scalping wings, and two of them can be pulled by a jeep or small tractor. It has successfully planted various shrubs, forbs, and grass.

Hydraulic Seeder-Mulcher. The hydraulic seeder-mulcher can apply seed, fertilizer, and soil amendments, including wood fiber mulch, through a hydraulic spray 20 to 200 feet on steep slopes, without operating a prime mover on the slopes. Tank capacity is 150 to 3,000 gallons of a water slurry, with 3 to 6 percent solids.

Rotary Spreader. Rotary spreaders broadcast seed, granular or pelletized herbicides, or fertilizers 8 to 50 feet, with a hopper capacity of 35 cubic feet or 2,500 pounds, and can be attached to light tractors.

Seed Dribbler. Seed dribblers mount on each side of a D-8 or similar size crawler tractor and dribble seed onto the tracts, which carry it forward to drop on the ground and be pressed into the soil. Hopper capacity is 740 to 925 cubic inches.

Transplanting

Transplanting is more time consuming than seeding, but it has been successful in some areas where direct seeding has failed. Transplants, commercial or wild, must be kept moist until planted. Accepted nursery practices should be followed. Native stock, well

adapted to the site, is preferred. Transplanting should include selection of vigorous stock, careful removal to reduce root damage, placement to avoid sunscald, proper pruning to reduce transpiration, and support to prevent windthrow. Providing water and fertilizer aids rapid root growth and survival. Such care is not always practical, but needless damage to transplants should be avoided (Larson 1980).

Large numbers of seedlings can be planted readily with a seedling planter, a tractor-drawn implement that opens furrows for bare-root tree or shrub seedlings and packs soil around them. An operator sits in the planter to place the seedlings in the furrows at selected intervals, at a rate of 1,000 to 1,500 seedlings per hour. Saplings and large shrubs can be transplanting with a combination tree spade and tree transport trailer.

When seedlings are unavailable, cuttings and suckers can be used. Root, stem, or leaf cuttings of many plants will develop roots when placed in a suitable rooting medium, after which time they can be transplanted. Suckers of adventitious root buds should be removed in the dormant season by digging down and cutting the shoots from the parent plant, and then transplanting (Yoakum et al. 1980). Hartman and Kester (1975) described these techniques in detail.

INTEGRATED MANAGEMENT OF TIMBER AND WILDLIFE

Wildlife biologists recognize that forest management practices have a tremendous potential for affecting wildlife and fisheries habitat positively or negatively. This results from the vast areas affected by forestry operations. Some silvicultural practices eliminate or are detrimental to wildlife, while others can be used to improve wildlife habitat.

Timber Harvest and Wildlife

The USDA Forest Service's basic approaches to integrated timber and wildlife management are featured species management (USDA Forest Service 1971), and management for species richness (USDA Forest Service 1973b, 1975). With featured species management, forest management is adapted to meet the habitat requirements of a specific wildlife species, and all wildlife species with similar or overlapping habitat requirements benefit.

Forests generally have six successional stages. More wildlife species are associated with some stages than with others (Table 4-10), which influences management for species richness. To produce wildlife and timber together, both wildlife systems require manipulation of five variables (Hall and Thomas 1979): scheduling of silvicultural treatments, arrangement of stands in time and space, stand condition, size of treatment area, and land (habitat) type.

The main silvicultural systems are clearcutting, seed-tree, shelterwood, single-tree selection, and group selection (Society of American Foresters with Cooperation of The Wildlife Society 1981,

Table 4-10. Life forms of wildlife relative to successional stages.

Life Form	Reproduces	Feeds	No. of Species	Example	Orientation	Grass-Forb	Shrub-Seedling	Pole-Sapling	Young	Mature	Old-Growth
1	In water	In water	1	Bullfrog							
2	In water	On the ground, in bushes, and/or in trees	9	Long-toed salamander, western toad, Pacific treefrog	R F	4 4	3 3	4 4	4 4	4 4	4 4
3	On the ground around water	On the ground, and in bushes, trees, and water	45	Common garter snake, killdeer, western jumping mouse	R F	4 5	5 6	4 4	5 4	6 5	6 5
4	In cliffs, caves, rimrock, and/or talus	On the ground or in the air	32	Side-blotched lizard, common raven, pika	R F	5 9	6 8	4 5	4 5	4 5	5 7
5	On the ground, without specific water, cliff rimrock, or talus association	On the ground	48	Western fence lizard, dark-eyed junco, elk	R F	3 13	12 15	12 14	6 14	7 14	5 13
6	On the ground	In bushes, trees, or in the air	7	Common nighthawk, Lincoln's sparrow, porcupine	R F	0 1	2 2	1 2	1 2	1 1	0 0
7	In bushes	On the ground, in water, or in the air	30	American robin, Swainson's thrush, chipping sparrow	R F	1 7	8 11	8 11	6 11	6 10	4 8
8	In bushes	In trees, bushes, or in the air	6	Dusky flycatcher yellow-breasted chat, American goldfinch	R F	0 1	1 2	1 2	1 2	1 2	1 2
9	Primarily in deciduous trees	In trees, bushes, or in the air	4	Cedar waxwing, northern oriole house finch	R F	0 1	0 2	0 2	0 2	0 2	0 1

Table 4-10 (continued). Life forms of wildlife relative to successional stages.

Life Form	Reproduces	Feeds	No. of Species	Example	Orien-tation	Grass-Forb	Shrub-Seedling	Pole-Sapling	Young	Mature	Old-Growth
10	Primarily in conifers	In trees, bushes, or in the air	14	Golden-crowned kinglet, yellow-rumped warbler, red squirrel	R F	0 1	1 5	4 10	9 13	12 13	12 13
11	In conifers or deciduous trees	In trees, in bushes, on the ground, or in the air	24	Goshawk, evening grosbeak, hoary bat	R F	0 12	1 16	8 18	14 19	19 20	16 19
12	On very thick branches	On the ground or in water	7	Great blue heron, red-tailed hawk, great horned owl	R F	0 6	0 5	0 4	2 5	5 6	5 6
13	In own hole excavated in tree	In trees, in bushes, on the ground, or in the air	13	Common flicker, pileated woodpecker, red-breasted nuthatch	R F	0 2	0 2	0 1	5 5	9 10	9 10
14	In a hole made by another species or in a natural hole	On the ground, in water, or in the air	37	Wood duck, American kestrel, northern flying squirrel	R F	0 15	0 15	3 14	11 15	23 22	23 22
15	In a burrow underground	On the ground or under it	40	Rubber boa, burrowing owl, Columbian ground squirrel	R F	12 17	15 17	13 16	13 16	15 17	15 17
16	In a burrow underground	In the air or in the water	10	Bank swallow, muskrat, river otter	R F	3 5	3 5	3 5	3 5	3 5	3 5
		Total:	327								

[a]Species assignment to life form is based on predominant habitat use patterns in Blue Mountains of Oregon.

R = Number of species reproducing
F = Number of species feeding

Source: Thomas et al. 1979, Hall and Thomas 1979

Burns 1983, USDA Forest Service 1983, Wenger 1984). Single-tree selection and group selection produce uneven-aged stands; the other methods produce even-aged stands. Although uneven-aged management can be useful to wildlife, even-aged management is more beneficial (Hall and Thomas 1979, Table 4-11). Forest economics and species' regeneration requirements generally dictate the system used on each forest type. In general, although there are many exceptions, the shelterwood system is most beneficial to wildlife because it couples moderate initial habitat loss with substantial habitat improvement.

Clearcutting

Clearcutting is the most commonly used silvicultural system. To consider wildlife fully, the distribution, size, and shape of clearcuttings (and intermediate cuttings) must be based on habitat requirements (such as home range), location of roads, drainage ways, bodies of water, farmlands, soil and timber types, terrain, pattern and size of ownership, and management objectives. Use of clearcuts by wildlife is influenced by adjacent forest stand structure (Northern Region, USDA Forest Service and Montana Department of Fish and Game 1978). The key to successful regulation of timber age classes for producing both timber and wildlife with minimum impact on timber yields and costs is long-term planning of cutting schedules for small units of land (Roach 1974). Once the distribution of clearcut areas is set, the pattern is difficult and expensive to alter (Halls 1973).

Design of Clearcuts

Although clearcuts remove cover and food, their impact can be modified with planning and care. On wooded units of about 1,000 acres, the Missouri Department of Conservation recommends that 5 percent of the area be in permanent clearings; of the remainder, 10 percent should be in seedlings, 20 percent in saplings, 30 percent in pole stage, and 40 percent in sawlog timber of which 10 to 20 percent should be harvested every 10 years (Burger 1973). Where aspen occurs, for example, deer population can be increased by cutting more aspen to stimulate sprouting and browse production (Table 4-12).

Those involved in wildlife habitat improvement must understand forestry operations and work with the forester, for the forester has numerous opportunities to improve wildlife habitat throughout the timber rotation at little or no expense to timber production (Wenger 1984). Wenger (1984) described wildlife habitat improvement practices within a timber compartment for the major forest associations in the United States. The Society of American Foresters with Cooperation of The Wildlife Society (1981) described silvicultural systems with wildlife concerns for the major forest associations in the United States.

Table 4-11. Comparison of characteristics of forests managed by even-aged and uneven-aged methods.

Characteristic	Even-aged	Uneven-aged
Harvest method	Clearcut Shelterwood Seed tree	Single-tree selection Group selection
Type of trees	Usually shade intolerant (shelterwood cut may produce even-aged stands of shade-tolerant species)	Shade tolerant
Stand appearance	Uniform tree height in each stand, except for a few years after shelterwood or seed-tree cut. Often esthetically unattractive, especially the first few years after cutting.	Great variation in heights of trees, although if group selection is used with groups larger than 1 acre, appearance is like small even-aged stands.
Forest appearance	A patchwork of stands of various ages	Esthetically acceptable. A large expanse of uniformly mixed sizes of trees
Type of wildlife use	Mobile species adapted to early successional and mixed successional stages	Species adapted to mature forest conditions

Source: Robinson and Bolen 1984

Clearcut Design for Particular Species

The shape of the cut is very important in designing clearcuts. Patch cuts are best. The size of the cut is not as important as the width. The narrower and longer the clearcut, the more wildlife home ranges are affected. Irregular edges and mosaics to maximize edge effect are preferred.

Ruffed Grouse. Ruffed grouse, the least mobile of the major forest wildlife species, need three age classes of aspen: dense sucker stands less than 10 years old for brood cover; sapling- and pole-stage stands 10 to 25 years old for adult wintering and breeding

Table 4-12. Relationship of white-tailed deer densities to aspen cutting.

Ac/mi^2 cut	$Deer/mi^2$
20 or more	11 - 20
40 or more	21 - 30
100 or more	31 - 40
200 or more	41 - 50

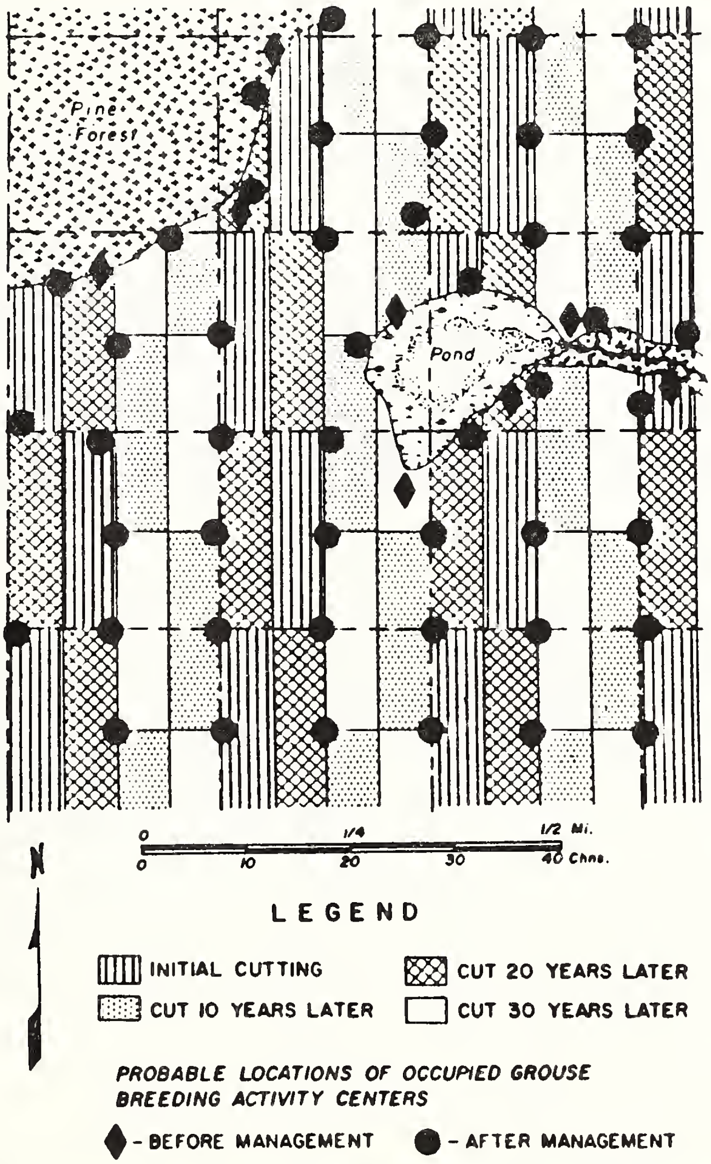
Source: Graham et al. 1963

cover; and older male aspen for food, wintering, and nesting cover. These different aspen age classes need to be in an area no more than about 40 acres and without tall conifers to conceal avian predators (Figure 4-20). Clearcuts should be in an east-west direction for best tree regeneration and deeper snow accumulation for snow roosting. This orientation enhances the availability of greens for grouse before egg-laying because the south-facing edge melts early (Rutske 1969). But such management is incompatible with best management for turkey, woodcock, gray squirrel, and white-tailed deer (Gullion 1972).

White-Tailed Deer. For white-tailed deer, clearcuts of 20 to 50 acres no wider than 10 chains are best (McGinnes 1969, Blymer and Mosby 1977). At least one unit should be cut every 8 to 10 years, and units should be separated by a 1/8- to 1/4-mile strip uncut for at least 10 years (Halls 1973). Dense slash, which severely impedes deer movement, should be removed. In the brush country of the Southwest, 150- to 300-feet-wide clear strips should be alternated with varying width strips of brush, until 25 to 30 percent of the brush is removed (Davis and Weishuhn 1982).

Moose. Areas of best potential for moose habitat management appear to be township-sized blocks, which should be 40 to 50 percent cut-overs less than 20 years old. Cutovers are best if composed of 5 to 15 percent black spruce-balsam fir and 35 to 55 percent water and aspen-white birch. Cutting units of about 200 acres should be as close together as possible (Peek et al. 1976).

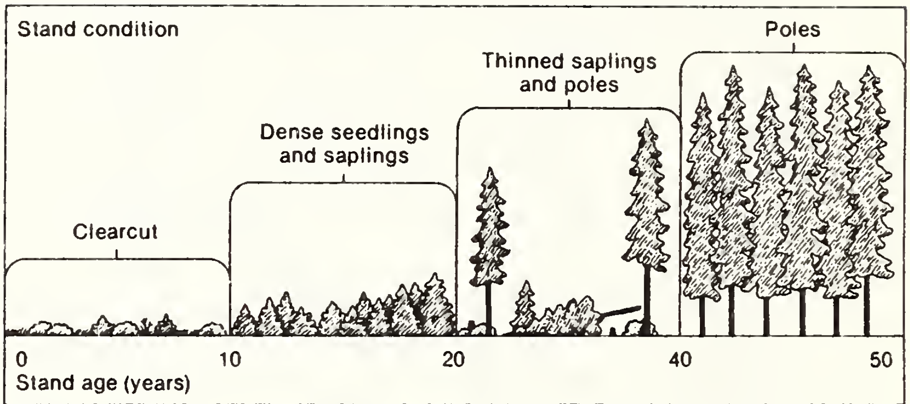
Mule Deer and Elk. If mule deer and elk occupy the same range, and requirements for elk are met, deer survival will be adequate (Thomas et al. 1979a). Optimum deer range should be 20 percent hiding cover, 10 percent thermal cover, 5 percent fawning cover, 5 percent hiding, thermal, or fawning cover, and 60 percent forage. Optimum elk range should be 20 percent hiding cover, 10 percent thermal cover, 10 percent hiding or thermal cover, and 60 percent forage, all of which may overlap somewhat (Figures 4-21 and 4-22).



Extensive commercial timber harvesting could be done in aspen or hardwood forests in a manner which should substantially benefit Ruffed Grouse and other forest wildlife species. Each of these rectangular strips consists of 10 acres, and 160 acres could be cut from a square mile in each operation, spaced at 10 year intervals. On the other hand, cuttings could be at 5 year intervals, cutting half as much each time.

Figure 4-20. Timber harvesting in aspen forests to benefit ruffed grouse.

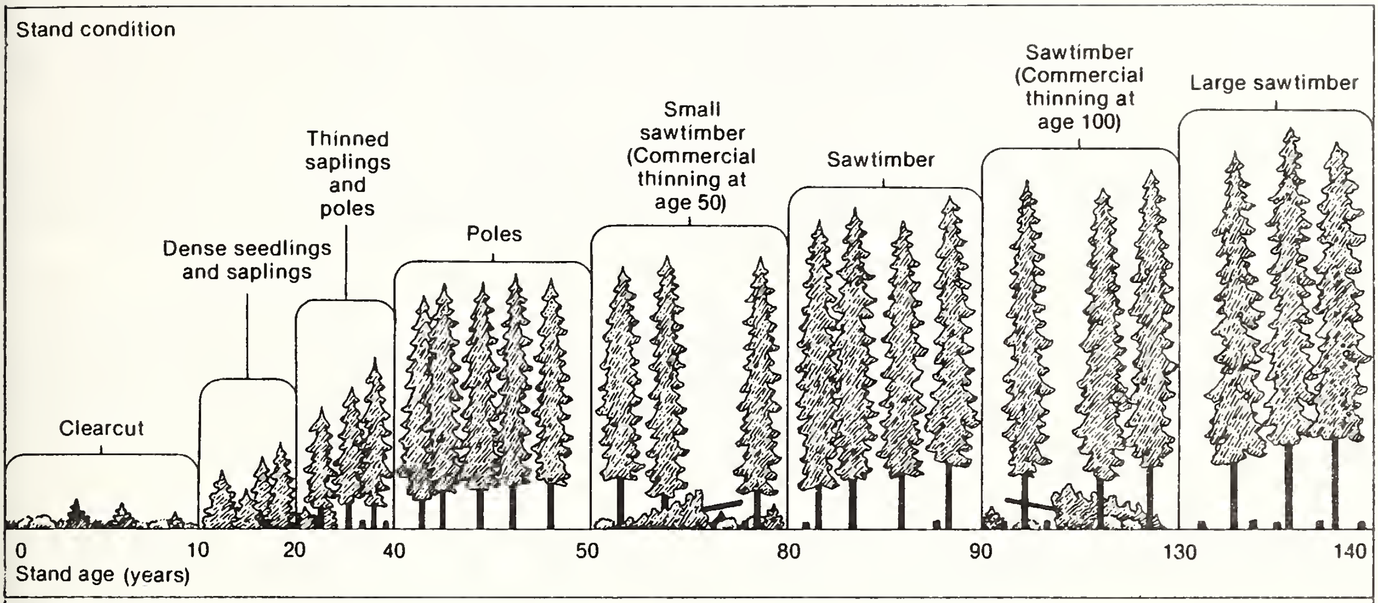
Source: Gullion 1972



Habitat for elk			
Forage area Forage is abundant.	Hiding cover Sight distance is less than 61 meters (200 ft) from age 10 to 20 or 20 percent of the rotation.	Forage area Half the trees are thinned at stand age 20 to select the best crop trees. The area now becomes a forage area and hiding cover is destroyed.	Thermal cover As the trees grow, crowns close and tree height reaches at least 12 meters (40 ft). Thermal cover is provided for 10 years or 20 percent of the rotation.

Figure 4-21. 50-year rotation designed for optimum elk habitat.

Source: Hall and Thomas 1979



Habitat for elk						
Forage area Forage is abundant	Hiding cover Sight distance is less than 61 meters (200 ft) from age 10 to 20 years or 7 percent of the rotation. One-quarter of the trees are thinned at stand age 20 to encourage growth but maintain hiding cover for 30 years or 20 percent of the rotation.	Thermal cover As the trees grow, crowns close and tree height reaches at least 12 meters (40 ft). Thermal cover is provided for 10 years or 7 percent of the rotation.	Forage area About 30 percent of the trees are removed in a commercial thinning. Thermal cover is destroyed and the area is now a forage area.	Thermal cover Tree crown cover is now over 70 percent. Thermal cover is provided for another 10 years or 7 percent of the rotation.	Forage area A second thinning removes another 30 percent of the trees, destroys thermal cover, and creates a forage area.	Thermal cover Thermal cover is restored the last 10 years prior to regeneration cut. Three 10-year periods of thermal cover amount to 30 years or 20 percent of the rotation.

Figure 4-22. 100-year rotation designed for optimum elk habitat.

Source: Hall and Thomas 1979

For maximum use of the area by elk, cover areas and clearcut areas should be less than 1,200 feet wide. Hiding cover for deer and elk should be 50 to 80 percent closed canopy, 10 to 30 acres, and 600 to 1,200 feet wide, with most overstory trees and shrubs at least 6 feet high (USDA Forest Service 1983). Thermal cover for deer and elk in spring, summer, and fall should be 70 to 90 percent closed canopy at least 40 feet high, and 30 to 60 acres. Hiding cover conditions constitute winter thermal cover, except the minimum size necessary is 30 acres. The USDA Forest Service (1983) listed basal area needed in stands of some tree species used for deer and elk hiding cover.

Small Game and Nongame Species. Most small game and nongame species benefit most from edge produced by small cuts (Patton 1974). For a species like the pileated woodpecker that requires old-growth timber, a 240-year rotation with cutting units of 300 acres (to correspond with its territorial requirements) is best.

Forest Fragmentation

Some wildlife species require unbroken stretches of contiguous forest for one or more seasons annually (Schoenfeld and Hendee 1978, Robbins 1979). Such species tolerate little or no timber harvesting or other human disturbance. Many songbird species wintering in the tropics depend on large unbroken tracts of forest during the U.S. breeding season (Webb et al. 1977, Robbins 1979). For example, the Kentucky warbler needs at least 82 acres, and the ovenbird at least 27 acres or they leave the area.

Species with normally low densities generally have large home ranges. These low-density species are very susceptible to forest fragmentation, depend on old-growth forests, and avoid edges. Natural areas can serve as a nucleus for population maintenance of low-density species where they are contiguous with managed forests. Otherwise, an orderly timber harvest rotation program with large undisturbed contiguous tracts is best.

Fruit and Mast

Fruit is an important summer and fall food source. Ordinarily the product of openings, open forests, and cutovers, fruit is not normally produced in quantity and variety under the canopy of a well-stocked forest.

Mast, which consists of seed mainly from oak, beech, hickory, walnut, butternut, hazelnut, and conifer, is an important food source in late summer, fall, and winter (Table 4-13). Of the mast producers, oak is the most important because of its variety, abundance, distribution, and wood. If oaks are managed in an even-aged system, a ratio of two trees in the black oak group to one in the white oak group is desirable. This mix will produce 100 pounds per acre of acorns (Shaw 1971). Production of acorns varies with species (Tables 4-14, 4-15, and 4-16). Oak stands of different ages can be interspersed to provide optimal habitat diversity for wildlife (Table 4-17).

Table 4-13. Acorn yields and wildlife uses.

	Species and Population of Animals (acres per animal)					
Dietary Needs	White-tailed Deer (20)	Gray Squirrel (2)	Fox Squirrel (3)	Turkey (50)	Bobwhite Quail (5)	Total
Pounds of food required per animal per day	5.0	0.2	0.3	0.5	0.02	
Pounds of acorns required						
180 days	450.0[a]	27.0[b]	39.6[b]	68.4[b]	1.80[a]	586.8
300 days	750.0[a]	45.0[b]	66.0[b]	114.0[b]	3.00[a]	978.0
Pounds of acorns per acre required						
180 days	22.5[a]	13.5[b]	13.2[b]	1.4[b]	0.36[a]	50.9
300 days	37.5[a]	22.5[b]	22.0[b]	2.3[b]	0.60[a]	84.9

[a]For 50 percent of diet.
[b]For 75 percent of diet.

Note: Pounds of food required daily by each of five species of game, pounds of acorns required to supply 50 or 75 percent of the daily diet, and production of acorns by oaks (pounds per acre) necessary to satisfy requirements for 180 and 300 days, at population levels indicated.

Source: Goodrum et al. 1971

Reforestation and Wildlife

Under many forest conditions, the natural regeneration of a timber stand as an aftermath of logging or burning results in diversity of vegetation by age, form, and species. The increased seeding, sprouting, and suckering of a regenerating forest is favorable to wildlife. Forage production for ungulates increases for about 10 to 20 years after logging (Scotter 1980).

A seedling spacing of 10 by 12 feet or 12 by 12 feet is better for forage production than spacing of 6 by 6 feet or 6 by 8 feet. Forage production will be very low from crown closure to the first commercial thinning, and a crown closes fast with 6- by 6-feet spacing. Probably, 8 by 10 feet would be a reasonable compromise between the needs of wildlife and timber production (Halls 1973).

Usable habitat is lost when forest openings are planted. If a clearcut in hardwood were 40 acres, about 30 acres might be planted and the remaining 10 acres left to natural forest regeneration. With openings of 5 to 10 acres next to a road, at least half should be left open next to the road for recreational viewing (Figure 4-23). With openings of 5 to 10 acres not next to a road, leave an

Table 4-14. Pounds of fresh acorns per acre relative to basal area in Southern plains forests.

Basal area[a] per acre (square feet)	Black oak group[b]		White oak group[c]	
	9 - 14"	15"+	9 - 14"	15"+
2	2	5	6	6
4	4		11	12
6	6	14	17	17
8	8	19	23	23
10	11	24	29	29
12	13	28	34	35
14	15	33	40	41
16	17	38	46	47
18	19	42	51	52
20	21	47	56	58

[a]Applicable only to trees having healthy crowns extending at least one-third of total height.

[b]Includes southern red oak and blackjack oak.

[c]Includes post oak and white oak.

Source: USDA Forest Service 1969b

unplanted strip about one chain wide around the plantation (Figure 4-24). Openings larger than 10 acres could be planted as in Figure 4-25.

Intermediate Cuttings and Wildlife

Where needed, cover values of conifers should be preserved by maintaining 50 percent canopy closure (Rutske 1969). Opening the canopy increases browse, fruit production, and nesting habitat for birds. Most species nest between ground level and 10 feet (Preston and Norris 1947). Cutting all competing trees within 5 feet of selected crop trees (about 100 per acre at 20 by 20 feet) in a sapling-sized (1 to 5 inches diameter at breast height) stand of northern hardwoods, for example, produces 26 to 46 pounds of fresh browse per square foot of basal area (Stoeckler et al. 1958). For best seedling-browse production, areas containing mixed oak and cove hardwoods should have 88 to 100 square feet per acre basal area (Knierin et al. 1971). Loblolly-shortleaf pine forests should be thinned to a tree basal area of 60 square feet per acre to produce maximum deer browse. However, 70 to 80 square feet per acre may be a reasonable compromise with timber production when repeated at 5- to 8-year intervals (Halls 1973). Food-producing and den trees as well as uncommon trees that would add variety to the ecosystem should be preserved. Wenger (1984) described improvement practices for wildlife of the major forest associations in the United States.

Table 4-15. Pounds of fresh acorns per acre relative to basal area in mountain forests (dominant or codominant trees).

Basal area[a] per acre (square feet)	Black oak group[b]		White oak group[c]	
	9 - 14"	15"+	9 - 14"	15"+
2	5	7	4	5
4	9	14	7	11
6	14	21	11	16
8	18	28	14	22
10	23	35	18	27
12	28	42	21	33
14	32	49	25	38
16	37	56	28	44
18	41	63	32	49
20	46	70	35	55
22	50	77	39	61
24	55	84	42	66
26	60	91	46	72
28	64	98	4	78
30	69	105	53	83
32	73	112	56	89
34	78	119	60	94
36	82	126	64	100
38	87	133	67	106
40	92	140	71	111
50	115	175	89	138
60	138	210	106	166

[a]Applicable only to trees having healthy crowns extending at least one-third of total height.
[b]Includes northern red, black, and scarlet oaks.
[c]Includes chestnut and white oaks.

Source: USDA Forest Service 1969b

SPECIAL FOOD AND COVER CONSIDERATIONS

Creating Openings

Forest Openings

Grassy forest openings, the result of abandoned homesites (Figure 4-26) or of mechanical, chemical, or burning treatment, ideally are 1/2 to 1 acre large at 1/4-mile intervals for short-ranging species, such as quail and grouse, and 2 to 5 acres large at

Table 4-16. Pounds of fresh acorns per acre relative to diameter at breast height.

D.b.h (in)	Chestnut Oak	White Oak	Post Oak	N. Red Oak	S. Red Oak	Scarlet Oak	Black Oak	Water Oak	Blackjack Oak	Sand-jack Oak
4	-	-	0.15	-	-	-	-	-	-	0.73
6	-	-	0.78	-	-	-	-	-	-	1.7
8	-	0.29	1.4	-	-	-	-	0.57	0.42	2.7
10	0.9	1.9	2.0	0.4	0.49	2.5	1.1	2.7	1.7	3.7
12	3.0	3.6	2.6	2.2	1.0	3.9	1.7	4.9	3.0	-
14	5.0	5.2	3.3	5.7	2.0	5.6	2.3	7.1	4.3	-
16	6.0	6.9	3.9	10.0	3.7	8.0	2.8	9.4	5.6	-
18	8.1	8.6	4.5	14.5	6.4	12.1	3.4	11.6	6.9	-
20	8.9	10.2	5.1	15.8	10.5	14.8	4.0	13.9	7.9	-
22	9.8	12.0	5.8	17.1	16.3	17.5	4.6	16.2	9.6	-
24	10.1	13.6	-	15.4	24.1	17.9	5.2	18.5	10.9	-
26	10.5	15.2	-	13.8	31.7	18.3	5.8	-	-	-

Source: Shaw 1971

Table 4-17. Interspersion of different age oak stands for optimal mast production.

Diameter Class (in)	White Oaks			Black Oaks			
	Cow	White	Post	Blackjack	Sandjack	Southern Red	Water
4	-	-	41	25	78	20	-
6	-	-	42	56	92	21	59
8	-	38	57	76	90	50	47
10	-	25	64	90	95	59	83
12	-	-	69	85	-	68	90
14	75	-	73	100	-	78	100
16	50	90	-	83	-	81	-
18	100	90	73	67	-	85	100
20	-	-	76	-	-	83	92
22	-	-	76	100	-	92	-
24	-	-	-	-	-	100	100
26	-	75	-	-	-	100	-

Source: Shaw 1971

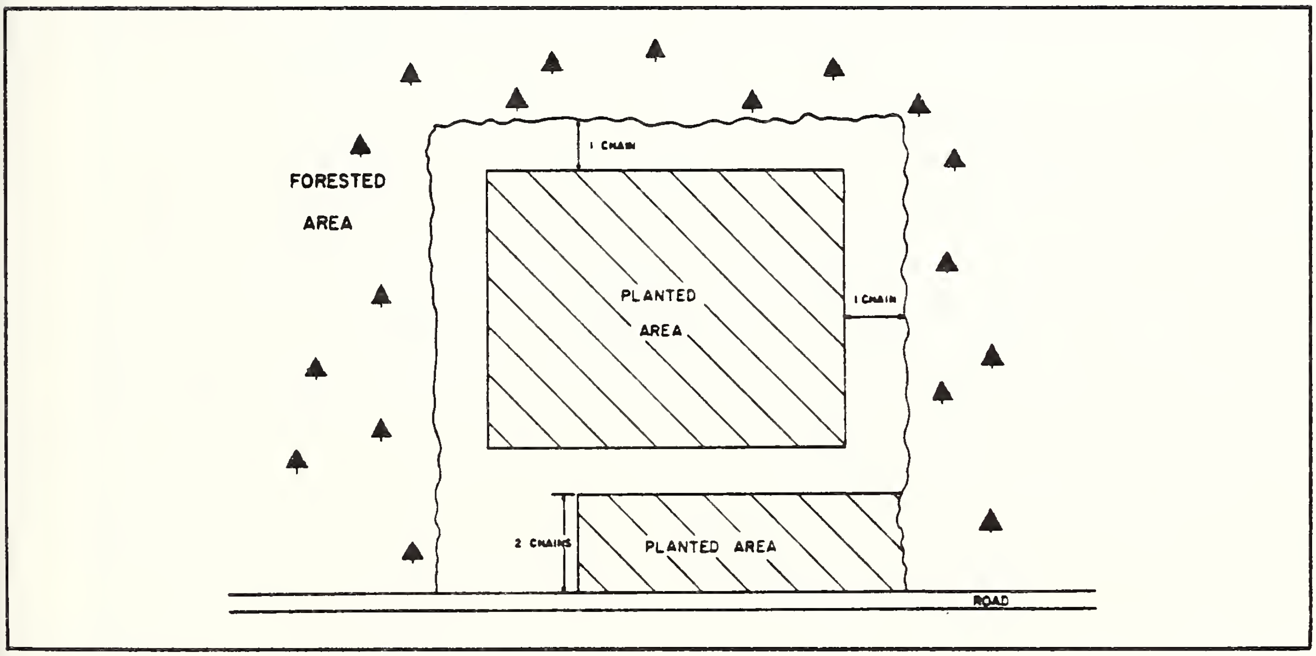


Figure 4-23. Suggested planting pattern for 10-acre forest opening next to a road.

Source: Rutske 1969

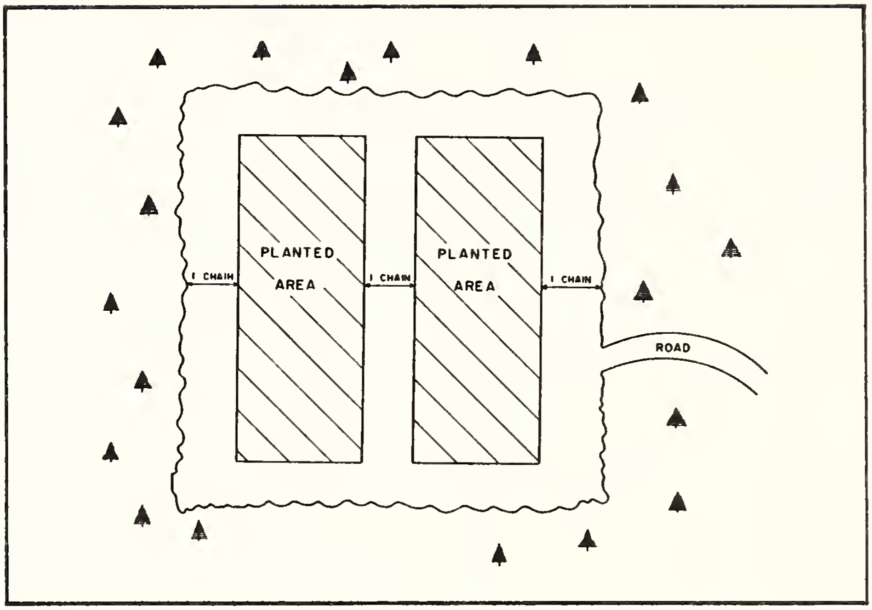


Figure 4-24. Suggested planting pattern for a 10-acre forest opening not adjacent to a road.

Source: Rutske 1969

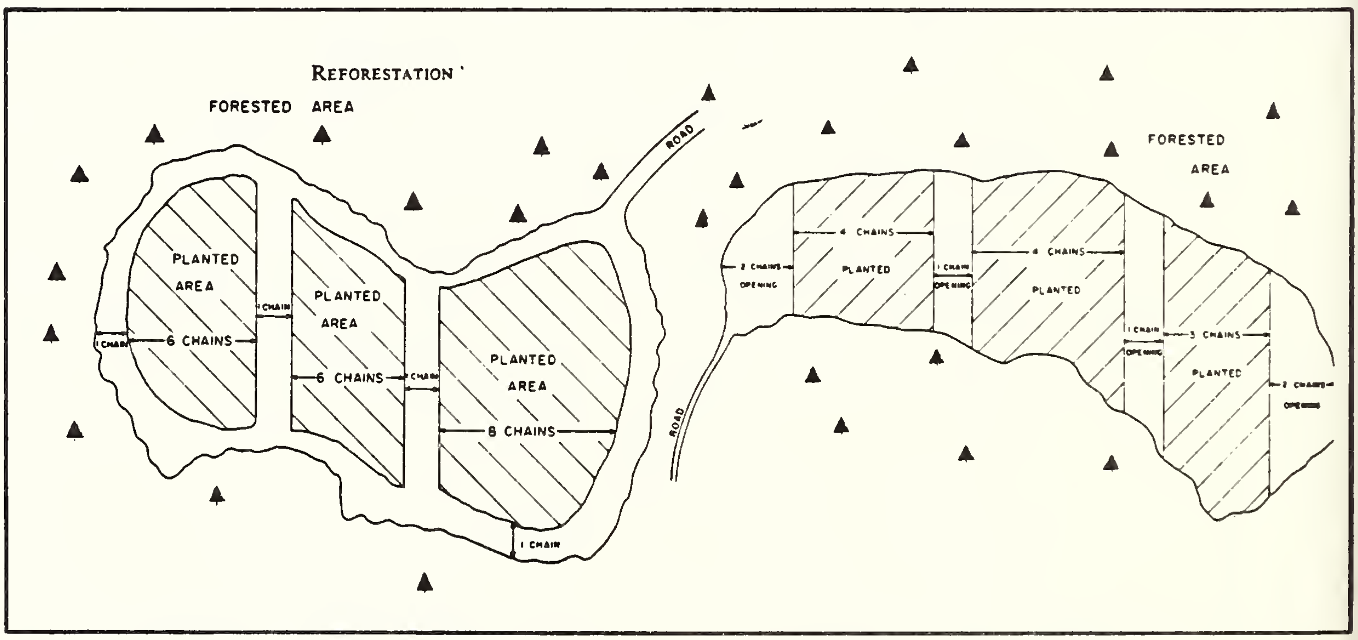


Figure 4-25. Suggested planting pattern for forest openings larger than 10 acres.

Source: Rutske 1969

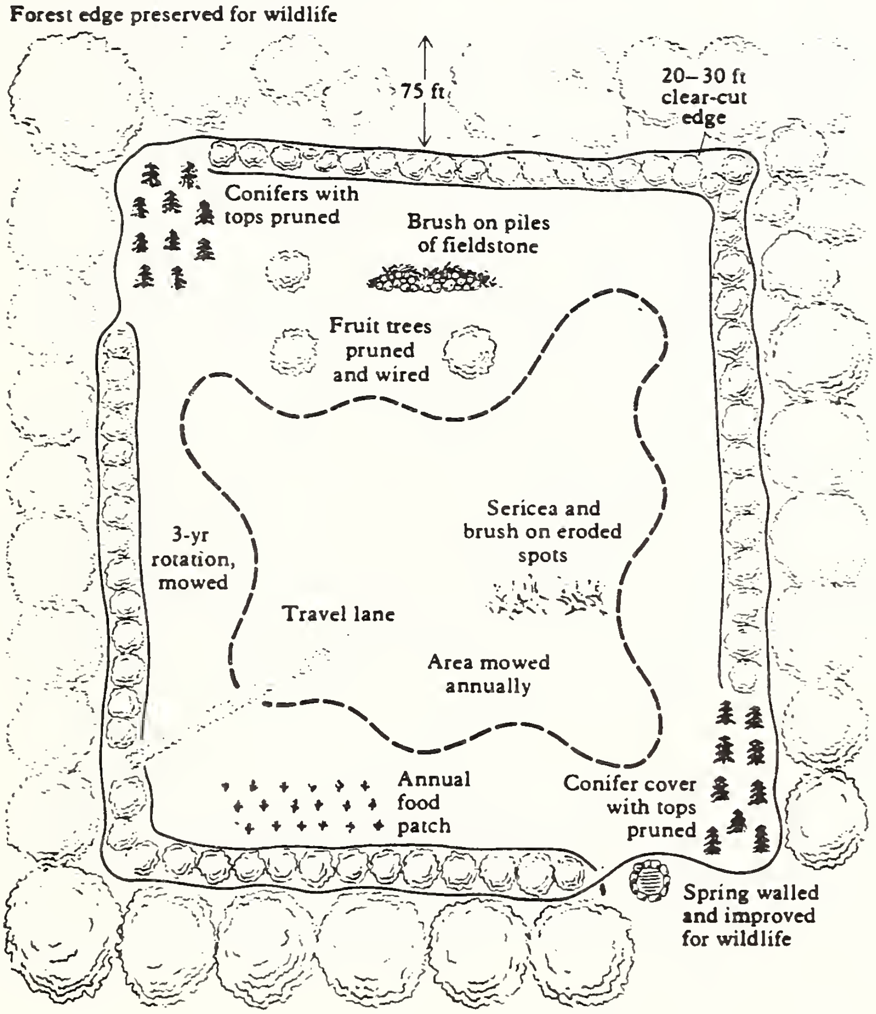


Figure 4-26. Maintaining old homesites as forest openings.

Source: Giles 1978

1/2-mile intervals for wider ranging species such as turkey and deer (McCaffery and Creed 1969, USDA Forest Service 1969b). Halls (1973) recommended 6 to 15 openings of 2 acres each for a 600-acre tract as acceptable for both wildlife and timber growing. In Wisconsin, up to 10 percent of forested lands managed for wildlife now are being opened (see Chemical Methods of Release in this chapter).

Openings should be at least three chains wide to enlist frost as an agent for natural maintenance (McCaffery and Creed 1969). Uncut strips in aspen stands should be left around openings to deter reestablishment of suckers when trees are cut. Shrubs should be encouraged by manipulating the forest edge of small openings rather than the opening itself. Where large stands of small pole timber occur, it should be ensured that the number of openings is as nearly optimal as possible. Sparse sawtimber stands do not need as many openings. Between these two extremes, spacing patterns should be developed to fit the terrain, cover, and wildlife requirements in the particular area.

A system of even-aged timber management simplifies developing a system of wildlife openings. Good spacing of regeneration cuts over the growing cycle might preclude the need for openings in some regions. After a final harvest cut, specified areas should be designated as permanent openings and excluded from timber regeneration (Figure 4-27). Browseways, utility pipelines, railroad rights-of-way, roadsides, firebrakes, trails, food patches, grass stubble, and ground cover should be included and managed as part of the openings system.

Browseways

Many chaparral-type brushfields are practically impenetrable to deer and offer mediocre habitat for other mammals and birds. These brushfields should be improved for wildlife by developing interspersions of brush sprouts and herbaceous vegetation through the creation of browseways and openings. The primary objective of such work is to develop edge, food, and access. The following guidelines apply to such projects:

(1) Selection of Areas

(a) Vegetation. Brush stands meeting the following requirements should be given priority for treatment: more than 20 percent of the stand composed of desirable browse species; slope, soil, and other factors are favorable; the density of the canopy is more than 70 percent; the average height of desirable species is more than 5 feet; and browse is unavailable or unpalatable because of the age of the stand.

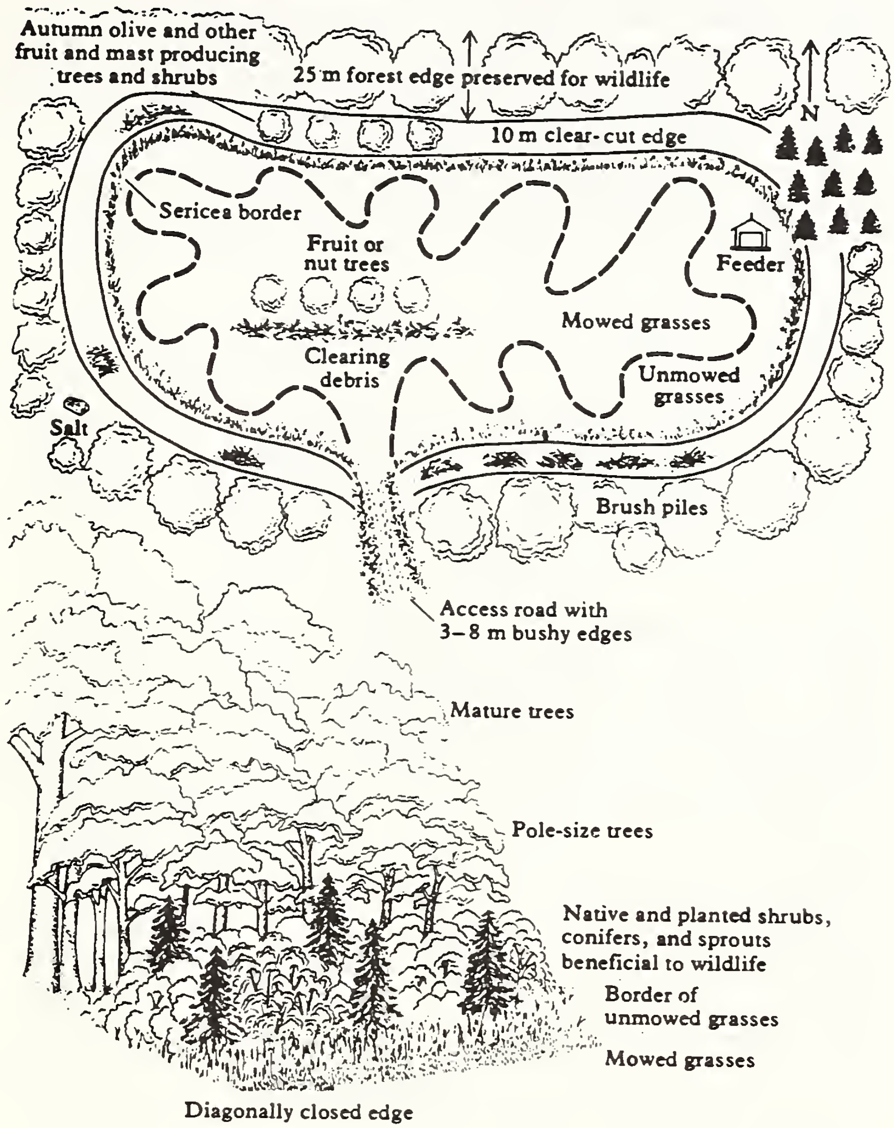


Figure 4-27. Features of forest wildlife clearing design and edge management.

Source: Giles 1978

(b) Slopes and Watershed Effect. On slopes of 0 to 20 percent, checkerboard and parallel browseways and openings may be constructed where other factors are favorable. Where slopes range from 20 to 30 percent, contour browseways and openings may be undertaken where soil or other factors are favorable, provided the slope is protected by contour strips or brush or grass planting, and less than 50 percent of the surface will be treated. If slopes exceed 30 percent for tractor work or 40 percent for handwork, browseways may be constructed only if work is largely on ridgetops and if adequate drainage or water breaks can be installed.

(c) Soils. Browseway strips that treat no more than 50 percent of the area on a contour basis probably have a limited effect on most soils. Soil considerations become increasingly important in direct relation to slope and to intensity of treatment. However, soils tend to have individual characteristics, particularly as to erodibility. Soils having a high rate of erodibility should have very limited or no treatment.

(d) Water. Areas selected should have at least seasonal water available within a reasonable travel distance for deer. Areas to receive large-scale intensive treatment, where no water is available, should have an adequate water supply development in conjunction with the proposed treatment. Ideally, spacing of water for deer should be at intervals of 1 mile or less. Deer will travel up to several miles to water but fare best where water is close.

(e) Extent. Present deer use and density (determined from pellet-group counts or direct observations) should be used as a guide in selecting size of areas. Areas of light deer use and density (1 to 3 deer days per acre, 1 to 5 deer per square mile) will require smaller amounts of treatment compared with areas of high density and obvious heavy browsing. Field examinations should be made to determine whether nearby burns will limit use of the proposed treatment area. The development of browseways in areas immediately next to type conversion projects or other openings is especially desirable.

(2) Treatment and Maintenance Methods

(a) Tools. Browseways and openings ordinarily are constructed with dozers, but heavy discs, rotary choppers, mowers, heavy chain drags, and rollers also may be used. Various herbicides applied by helicopter or ground equipment have been used to make browseways.

(b) Treatment. Methods of browseway treatment include extensive lanes, checkerboards, and contour parallels. The width and spacing of strips should be determined by soil erodibility, plant species, age, size of brush, and density of the deer population. Checkerboards or parallel strips are adaptable to slopes less than 20 percent. Contouring may be done on slopes up to 40 percent (30 percent with tractors). Irregular-edged treatment patterns are preferred over symmetrical straight-edged patterns, esthetically and practically. Crushing, mowing, or chopping makes existing plant species available for browsing and encourages abundant sprouting. The season of the year and amount of moisture present are important considerations to promote breakage (during treatment) or reduce occurrence of certain species. Chemical spraying may be used to trim back top growth, but use by deer may not be heavy enough to keep new growth in available forms (if dense stands of deadwood are left standing). Shaving encourages crown sprouting of existing species. While burning cannot be used to develop browseways, it can be used in small clearings to consume slash and promote seed germination.

(c) Maintenance. Where the amount of treatment is in balance with the deer population, browsing will hold sprouts of palatable brush species in available growth forms for 10 years or more. When maintenance is needed, the same techniques used in development work may be used.

Managing Special Areas

Rights-of-Way

Utility, pipeline, and even railroad rights-of-way can be managed to create a vegetation structure changing from grasses and forbs in the center to trees on the outside, thus forming a gradual ecotone. Ideally, about one-third of the corridor should be in a mixed shrub community, and two-thirds in a legume-grass mixture (Arner 1977). Plantings in rows are best along open areas such as cropland or grassland; plantings in clumps are best along areas bordering woodlands. Isolated shrub patches with some small trees interspersed within the herbaceous opening may be ideal for songbirds (Chasko and Gates 1982). Fruit-bearing species and woody plants should be used as screening along trails, roads, or other areas of public use. Plantings of conifers spaced 8 by 10 feet in clumps of 10 or more at each side of a road crossing will screen right-of-way development visible to travelers; however, it should be considered that such visibility may be desirable to enhance wildlife observation. Shrubby areas with small trees can be preserved in areas where the distance between power lines and ground is large, such as across stream valleys. In some instances, ponds could be constructed with no adverse effects to the utility line.

Roads

Roads can be useful for harvesting and observing wildlife in remote areas, but they also can be detrimental when they introduce disturbance to wildlife breeding and travel areas or allow excessive human access. Habitat improvement along road rights-of-way can thus be a necessary wildlife benefit; however, some improvements can be dangerous if increased density of ungulates causes increased collisions with vehicles. Low profile vegetation along road rights-of-way improves wildlife visibility and reduces road kill.

Generally, vegetation selected for roadside habitat improvement should be as unattractive as possible to ungulates, unless forest roads receive little fast-moving traffic. Fencing to prevent ungulate access to roads may be desirable, with properly located underpasses and wing fences to guide ungulates.

If right-of-way width permits, the planting ideas shown in Figure 4-28 could be followed. Plantings of shrubs and trees are clustered and boundaries are shaped with long sweeping curves to facilitate mowing. Grasses and forbs should be capable of remaining upright through winter for cover and spring nesting. Plant species should be selected for form, forage, resistance to tree invasion, and resistance against potential as disease hosts. For example, shrub species resistant to tree invasion include huckleberry, greenbriar, low blueberry, witchhazel, speckled alder, sheeplaurel, gray dogwood, nannyberry, staghorn sumac; species to be avoided as disease hosts include buckthorn next to cereal grains, gooseberry next to white pine, and red cedar (juniper) next to apple orchards (Leedy and Adams 1982).

Dead trees and trees with dead limbs should be retained in the outer perimeter for perching, feeding, and nesting. Leedy and Adams (1982) list species of plants valuable for habitat improvement along roads in various regions of the United States. Nearby borrow pits resulting from road construction can be connected to roadside and surrounding plant cover with travel lanes and improved for wildlife (Figure 4-29). Road surfaces can be used to collect water for distribution to wildlife.

Trails

Trails are forms of forest openings. Trails across south-facing slopes above a lowland brush area provide dusting and sunning sites, fill with snow to facilitate obstruction-free snow roosting by grouse, ensure early snow melt and thus early availability of green plants, and produce food-producing herbs and shrubs if the trail is wide enough (Rutske 1969). Seasonal and abandoned logging roads can serve as trails, and should be included in the forest opening system.

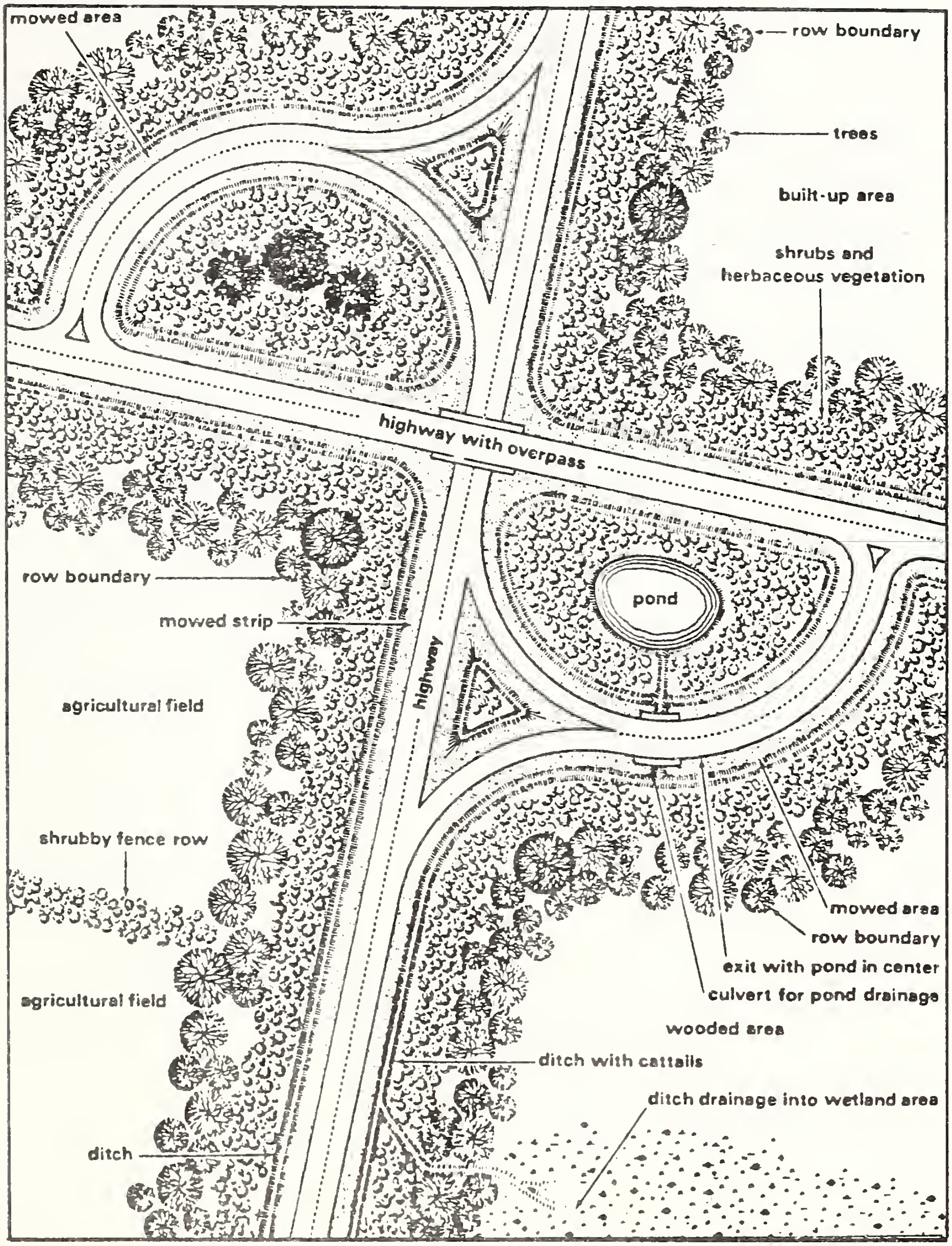


Figure 4-28. Sketch of planting pattern for highway right-of-way vegetation for wildlife habitat enhancement.

Source: Leedy and Adams 1982

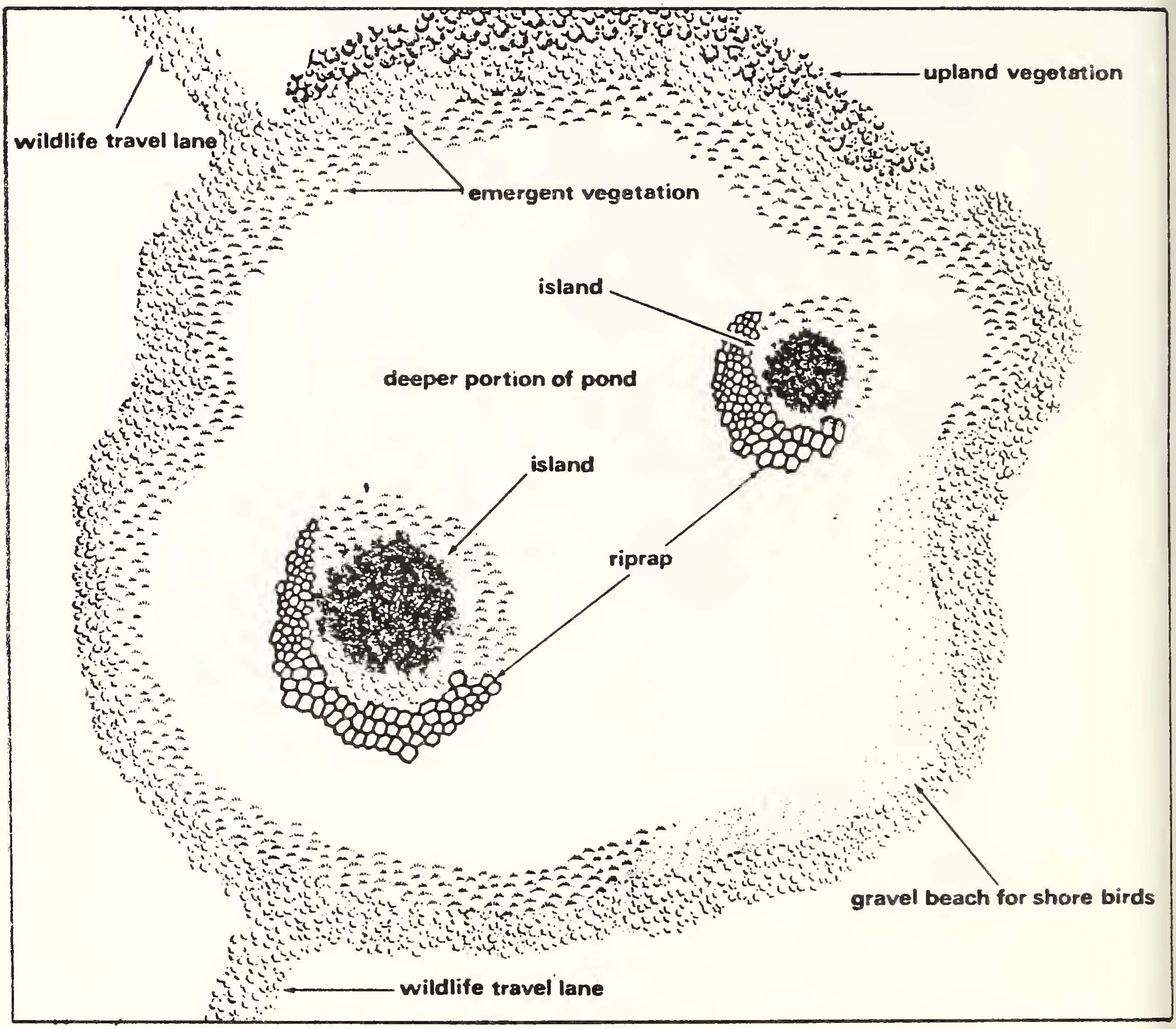


Figure 4-29. Borrow pit pond designed for waterfowl and other wildlife.

Source: Leedy and Adams 1982

Site preparation usually includes liming, fertilizing, and harrowing before seeding. Seed trails with clover. Table 4-18 shows application rates of lime that will produce a pH of 6.0 to 6.5, which is favorable to clover and most other crop plants (Gill 1957).

Food Patches

Even when food is adequate, food patches can be used to draw wildlife into camera, binocular, or gun range. These food patches and strips can be alternated with patches and strips of other vegetation to increase spatial heterogeneity and create edge. Although some plots may be 5 acres, the best plots are 1/8 to 1 acre, long and narrow or irregularly spaced, and within 1/4 mile of winter cover, preferably next to it. Recommended plants include corn, wheat, buckwheat, oats, barley, rye, flax, sorghum, millets, soybeans, clover, and domesticated sunflowers. For best winter cover and food combinations, adjacent patches of corn and forage sorghums should be planted, preferably with corn planted on north or west sides (Woehler 1982).

Early seeding ensures maturity. Acceptable soil conservation procedures dictate seedbed preparation. Soil should be tested to determine the amount of fertilizer needed. To provide needed cultivation, the U.S. Soil Conservation Service recommends drilling corn, sorghums, and sunflowers in rows 22 to 42 inches apart. For wheat, buckwheat, oats, barley, rye, flax, millets, and clovers, locally accepted drill spacing should be used. Double or triple seeding rates should be used with broadcast seeding and dragging of oats, barley, rye, and millets. Accepted full seeding rates or the following should be used:

Table 4-18. Application rates of lime to produce a pH of 6.0 to 6.5 (tons per acre)

Present pH	Light sand to sandy loams	Medium loams to silt loams	Silty clay loams to clay
5.0 or below	2.0	3.0	4.0
5.1 - 5.5	1.5	2.0	3.0
5.6 - 6.0	1.0	1.5	2.0

Grain species	Minimum rate/acre
Corn	7 lbs in 42-inch rows
Wheat, barley, rye	1 bushel
Buckwheat and oats	50 lbs
Flax	35 lbs
Sorghums	12 lbs in 24-inch rows
Millets	30 lbs
Soybeans	50 lbs in 42-inch rows
Clovers (white and ladino)	5 lbs
Sunflowers	5 lbs in 42-inch rows

Grass Stubble

For effective cover, grass stubble should be tall enough to conceal a crouching hen with brood, but short enough to enable a standing hen to see over it. Generally, this is 60 to 70 percent of the hen's height. For example, blue grouse are 10 to 14 inches tall and prefer cover 7 to 8 inches tall. Herbaceous cover of various growth forms is preferable to uniform stands of grass. For some species, such as blue grouse, a mixture of grasses, forbs, and low shrubs with little bare ground is best. Stubble height should be maintained at the desired height during the brooding season. Controlled grazing is one of the best methods to do this. Consult local wildlife agencies about appropriate species to plant for best height. Various species of gallinaceous birds prefer the following stubble height (USDA Forest Service 1969b):

Species	Cover height (inches)
Bobwhite quail	4 to 5
Hungarian partridge	5 to 6
Chukar partridge	5 to 6
Blue grouse	7 to 8
Sharptail grouse	8 to 10
Prairie chicken	10 to 12
Pheasant	10 to 12
Sage grouse	12 to 18

Ground Cover

Good ground cover for nesting and winter use consists of a mixture of herbaceous and shrubby vegetation. In many States, switchgrass is used because of its stiff stems and ability to support some snow or recover from the weight of excessive snow. Blackwell switchgrass, brome grass, and canary grass produced the best nesting cover for grassland nesting species in Wisconsin (Frank and Woehler 1969). Timothy and canary grass are best on muck or peat soils. Good herbaceous cover also supports higher densities of small mammals which, in turn, support mammalian and avian predators. Most State wildlife agencies, as well as the U.S. Soil Conservation Service in each State, provide information on the best species to plant and how to plant them.

Native grasses must be mowed, burned, or grazed often to break up the dense cover that will develop. Mowing should be done in late July or August after eggs have hatched and broods are gone. Rotation burning should be done in April, before nesting, every 3 to 5 years (Kirsch and Kruse 1973).

Odd Areas and Vegetative Islands

Odd areas--eroded areas in crop fields, bare knobs, sinkholes, sand blowouts, gullies, rockpiles, rock outcrops, borrow pits, gravel pits, pieces of good land cut off from the rest of the field by stream, drainage ditch, gully, or center pivot irrigation--may need little or no improvement, except protection from fire and grazing. If food or cover plants are lacking, they should be added. At least half the odd area should be in good ground cover of grasses and legumes. Site preparation on untillable lands is limited to scalping or herbicides (Woehler and Dumke 1982). Apply granular herbicides in fall, or scalp strips 18 inches wide and 2 inches deep for planting shrub seedlings.

Where winters are severe, 25 to 50 adapted conifers can be planted in such areas about 8 feet apart in a clump so that they retain lower limbs for cover close to the ground as long as possible. Plant from one to three rows of fruit-producing shrubs spaced 3 to 4 feet apart around the conifers for nesting cover, food for songbirds, and escape cover (if the shrubs are thorny) (Anderson 1969). Shrub lespedezas, a useful legume, should be in rows 3 feet apart, with the plants 2 feet apart in the row.

West of the Mississippi, the odd area should be planted as a windbreak. To improve such areas for pheasants and other wildlife, two rows of such hardy shrubs as wild plum, sand cherry, Russian olive, or bush honeysuckle, can be planted on the west and north sides. Then a 100-foot-wide strip of sweetclover should be sowed next to the shrubs. A block of at least 100 conifers or hardwood trees (like boxelder, green ash, or soft maple) should be planted in the southwest corner. This type of planting should be at least 1 acre.

East of the Great Plains, native shrubs will often establish themselves naturally in odd areas protected from fire and grazing, and only a grass-legume mixture may need to be planted. Half the herbaceous area should be sprayed or mowed every 2 years to reduce invasion of woody plants. Local wildlife managers and soil conservationists should be consulted in choosing plant species and in determining the soil's need for lime and fertilizer.

Type conversions of brush to grass should be planned so that islands and travel lanes of brush cover are left to serve the needs of wildlife.

Deer Yards

Improvement and maintenance of deer yards requires two approaches: reduced cutting for overhead shelter and increased cutting for browse production. Only a white cedar yard rates well in both categories (Table 4-19). It may be possible to shift some deer from one wintering area to another by cutting timber on summer range (Gill 1957). Otherwise, frequent small clearcuts or shelterwood cuts should be made in winter in areas next to the yard for browse production. Stumps should be cut low. Stumps 6 to 12 inches high sprout more vigorously than stumps 18 to 24 inches high, and may remain in reach of deer longer (Gill 1957).

To allocate cutting compartments, survey deer yards and outline the timber types. Create about five age classes of 15 to 20 years difference in a rotation of 80 to 100 years (Verme 1965). Cut long, narrow strips leaving alternate rows of the same width for cover and seed source to develop a storied age structure (Figure 4-30). The five cutting units in each compartment should be in block form to reduce the amount of edge and browsing of seedlings. Intermediate cuts should be made in adjacent units beginning at age 40 for cedar, and then every 40 years. Clearcutting cedar yields enough browse to sustain 400 white-tailed deer per 40 acres (Verme 1965).

Table 4-19. Timber stands rated good for shelter and food in deer yards

Shelter			Food		
Stand Type	Height (ft)	Canopy (%)	Stand Type	Height (ft)	Canopy (%)
Spruce-fir	35-64	41-70	White cedar	35-64	40
White cedar	35-64	70	Hardwoods-spruce-fir	35-64	41-70
Spruce-fir-Hardwoods	35-64	70	Spruce-fir-hardwoods	No stands rated mostly good	
Hardwood	No stands rated mostly good		Spruce-fir	Nearly all stands rated mostly poor	

Source: Gill 1957

Note: Minimal for desirable conditions in center of yard. For shelter, stands taller or denser are as good or better; for food, the reverse holds.

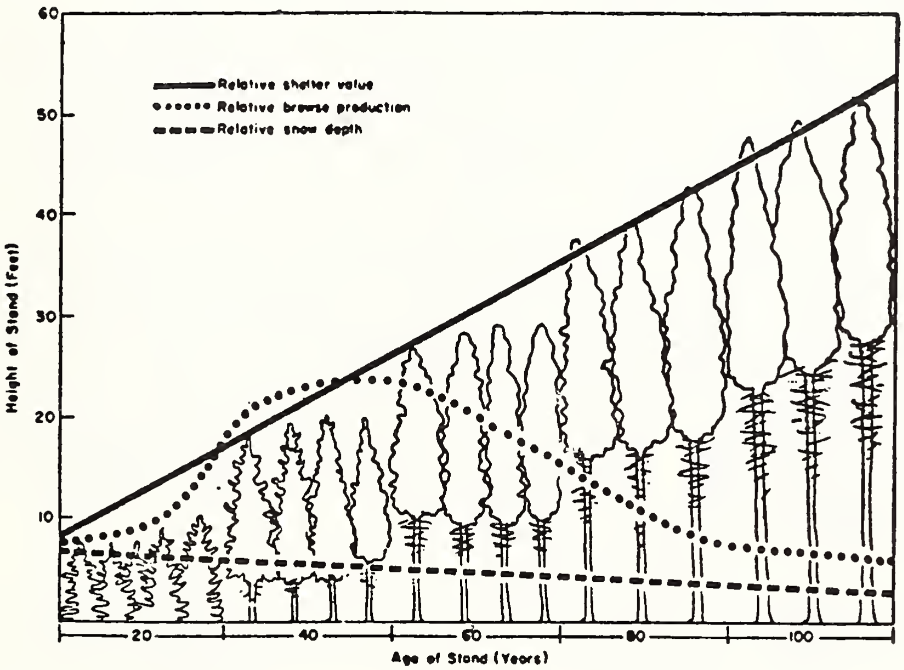


Figure 4-30. Optimum quantity and quality of browse or shelter for deer provided at different stages in the rotation cycle of even-aged timber.

Source: Verme 1965

Logging must be done annually. Plantations near deer yards can be designed to convert sites of poor quality hardwoods to favor deer (Gill 1957).

In addition to silvicultural methods, browse can be produced by bulldozing in spring, applying herbicides, and controlled burning (Gill 1957). Emergency winter feeding in deer yards involves half-cutting browse species too tall for deer or cutting browse species at the snow line for stump sprouting (Figures 4-31 and 4-32). Such feeding should be started when the snow depth is 20 inches without a supporting crust (Gill 1957).

Hedgerows and Windbreaks

Travel lanes of cover (of which hedgerows and windbreaks are the most obvious) should be established across extensive open areas to connect isolated cover, feeding, wallow, water, breeding or nesting, and winter areas. Browseways and removal of slash also are forms of travel lanes, opening impenetrable areas to wildlife.

Hedgerows. Hedgerows grow naturally along fences, if protected. Where no fence occurs, an 8-foot-wide strip or disk should be plowed where a hedgerow is desired. Fence posts should be set in a line or staggered about 20 feet apart down the center of the plowed strip. Wire or twine string should be run 4 feet high between the posts for bird perches. Bird droppings are laden with viable seed from which plants will grow almost as fast as those growing from rootstock. For such species as bobwhites and cottontails, at least a 660-foot hedge for every 40 acres of open country should be established.

Hedgerows with shrubs or a shrub-conifer mixture should be planted. After site preparation, two to four shrub stems per hole should be planted with 3 to 5 feet between holes. Conifers should be planted at a rate of 1 stem per hole, with 6 to 8 feet between holes. Space shrub rows 6 feet apart and conifer rows 8 feet apart to provide contiguous cover in 8 to 12 years (Dumke 1982). Conifers will need thinning at 10 to 15 years. A three-row hedge of one row of shrubs and two of conifers will provide a 25-foot-wide strip. Protection from grazing and fire is necessary. Without site preparation, plantings can be made along fence rows, in gullies, along streams, around ponds, springs, food patches, nesting grounds, breeding grounds, and other well-used wildlife sites.

For hedgerows consisting of shrubs only, at least four rows 30 feet long, spaced 6 feet apart, should be planted in early spring, and weed control should be established the first or second year (Woehler and Dumke 1982). Weeds are controlled most often with herbicides, but cultivation, mulches, clipping, and hand weeding also are effective. A triangular arrangement of fields, hedgerows, access roads, and gates is best (Figure 4-33). Plant hedgerows on south-facing slopes first, with the second choice of either east- or west-facing

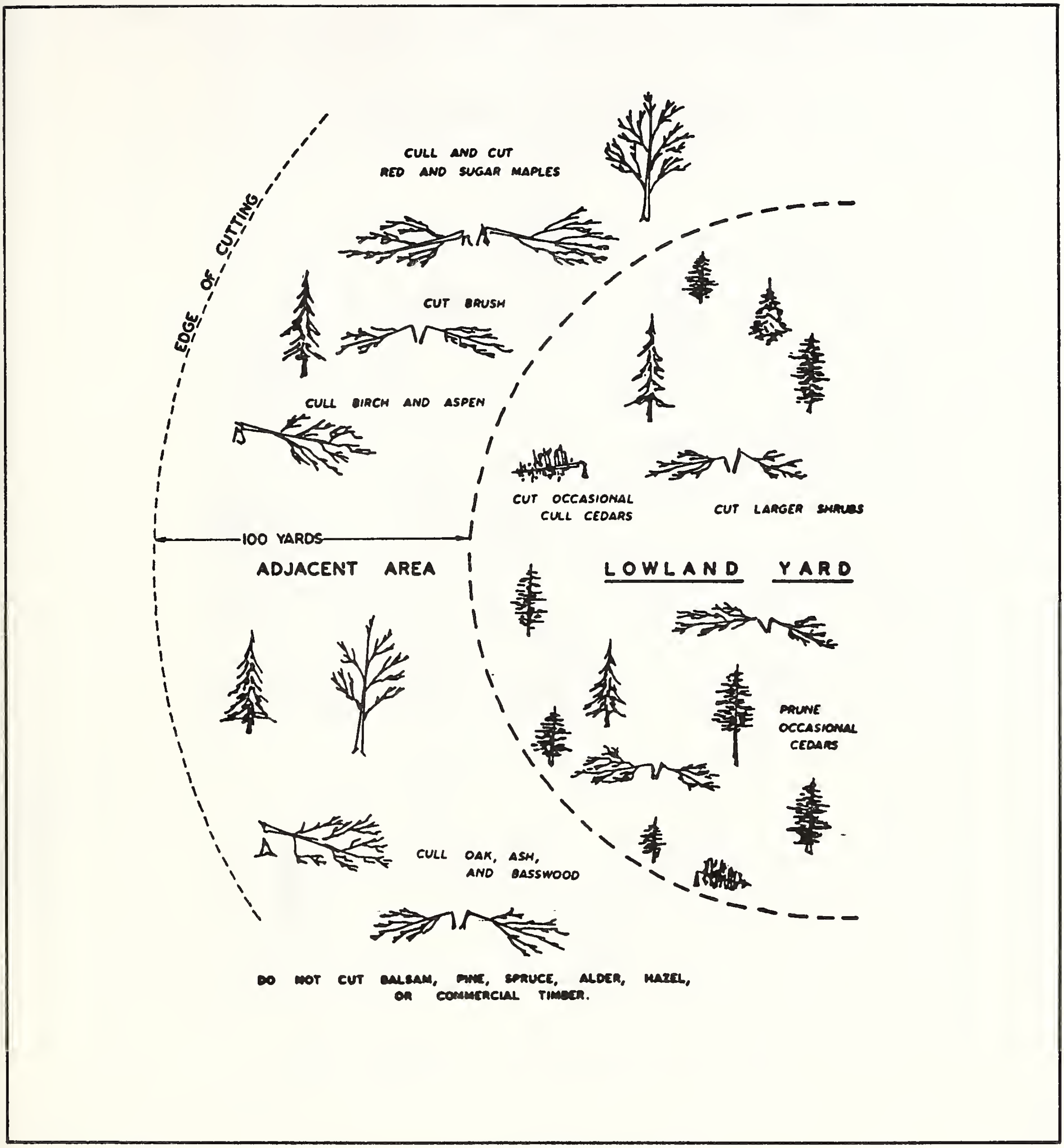


Figure 4-31. Improvement of deer yards by winter cutting of browse in lowland yarding areas having white cedar or balsam cover.

Source: Rutske 1969

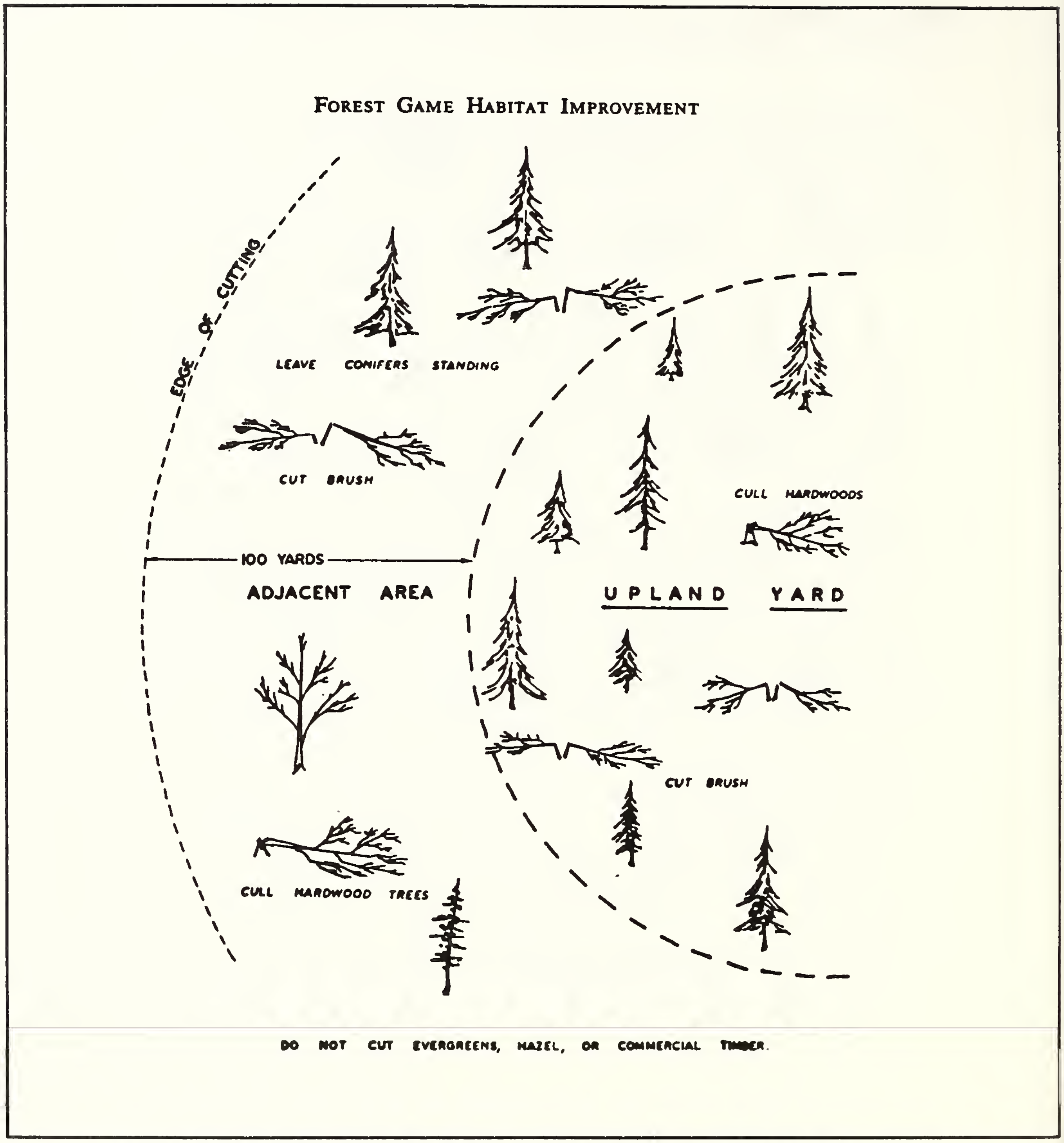


Figure 4-32. Improvement of deer yards by winter cutting browse in upland yarding areas of balsam, spruce, or pine.

Source: Rutske 1969

slopes. On leveled ditchbanks, it is preferable to plant north and west edges. Where large fields are to be divided, exposure to the southeast, south, and east should be considered, in that order. On slopes exceeding 3 to 4 percent, hedgerow and row crops should be separated with a 6- to 7-foot sodded border. Across a natural waterway, shrubs should be spaced to allow a vigorous grass-forb understory to develop. Woehler and Dumke (1982) describe species selection and characteristics.

Windbreaks. Windbreaks (shelterbelts) should consist of trees or a shrub-tree mixture planted at a right angle to the wind. Single-row windbreaks, in which shrubs and trees alternate in the row, are used on high-value land. In four-row windbreaks, typically the inner two rows are hardwood trees and the outer two are shrubs or conifers or both. In eight-row or more windbreaks, the outer four rows usually are shrubs or conifers (Anderson 1969). Where shrubs are used, they should be established first on the windward side. Patterns of rows may vary (Figure 4-34). Shrubs should be spaced 4 feet apart in rows 8 to 10 feet apart, conifers 6 to 8 feet apart in rows 8 to 10 feet apart. Hardwoods should be spaced 8 to 10 feet apart in rows 8 to 16 feet apart. The wider spacing should be used with wide-spreading trees like cottonwood and for all species in low rainfall areas. Windbreaks should be protected at all times from grazing and fire, and they should be cultivated regularly for at least 5 years in the West and 2 years in the East. They should be at least 100 feet away from the area to be protected. Preferably, windbreaks should have an undulating design (Figure 4-35) so that wildlife entering open areas will be protected from view on three sides. Windbreaks usually need 6 years of growth to be effective, but will last at least 50 years.

Retaining Wildlife Habitat After Logging

Brush Piles

When cover is limited, brush piles may be provided next to food patches and other plantings in forest openings and along rights-of-way. Brush piles should be spaced 200 to 300 feet apart from each other or from suitable ground cover and no more than 1/4-mile from water. Brush piles may be composed of living or dead limbs. When conifers and some deciduous trees are 6 to 8 feet tall, they can be half-cut in spring by cutting the trunk 3 to 4 feet above the ground, opposite the direction of fall. The cut should be made just deep enough so the trunk can be pushed over and still have a life-supporting connecting strip (Burger 1973). If the trees are taller than 8 feet, lower limbs can be half-cut and bent down, but large trees also can be half-cut. Dead brush piles should be at least 5 feet high and at least 10 to 15 feet long.

The base of brush piles can be rot-resistant logs like oak and locust, 6 inches or more in diameter, or even large stumps, old fence posts, large stones, metal grills supported by cinder blocks, or tractor tires. The logs should be placed parallel about 4 to 6 inches apart, with a second layer of large logs added on top at

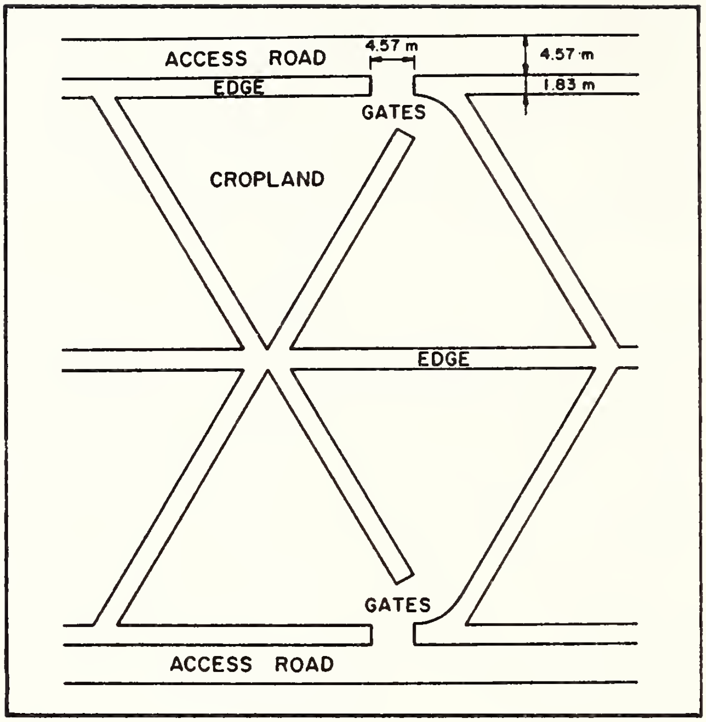


Figure 4-33. Hedgerows.

Source: Powers 1979

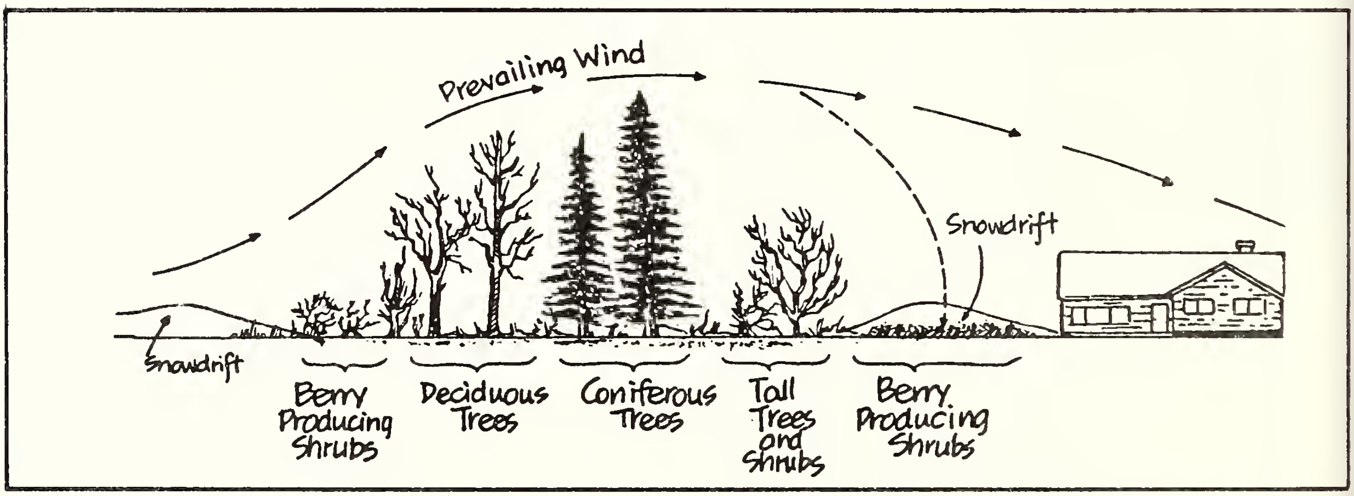


Figure 4-34. Windbreak design.

Source: Unpublished data, Alberta Agriculture; Alberta Energy and Natural Resources; Canadian Wildlife Service; Recreation, Parks and Wildlife Foundation

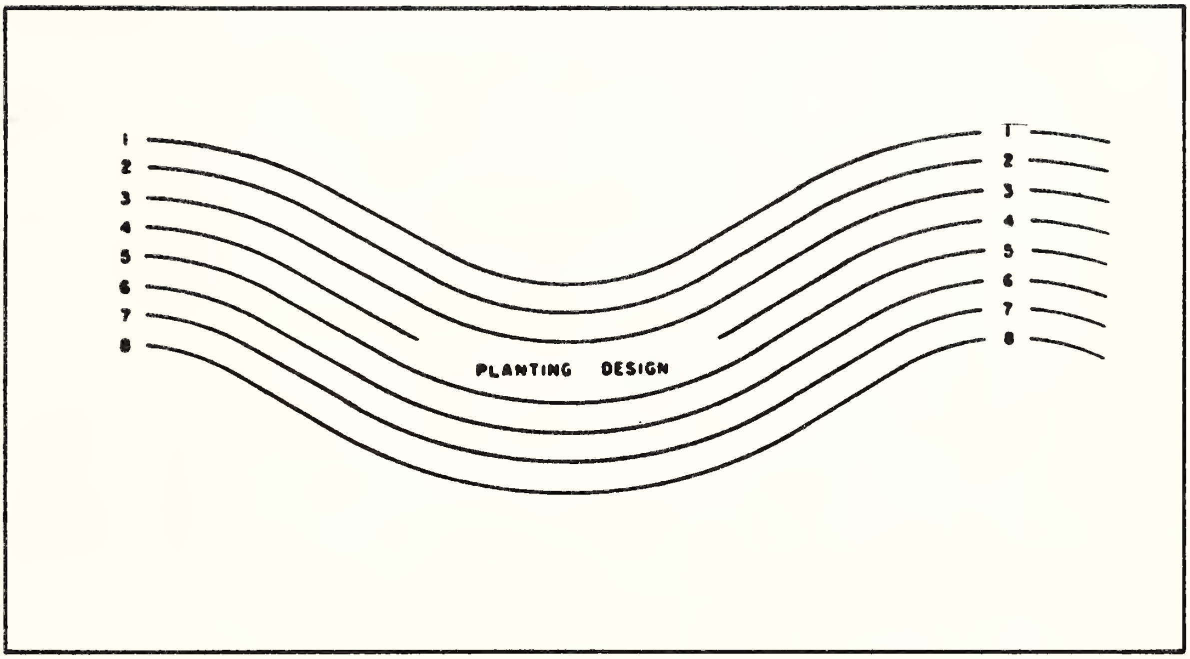


Figure 4-35. Undulating design of windbreaks that protect wildlife from view on three sides in opening.

Source: PFRA Tree Nursery (no date)

a right angle, and finally, finer woody material added in alternating layers (Burger 1973).

A 6-inch diameter tile drainpipe, 2-1/2 feet long, added to the soil at the edge of the brush pile near an animal trail, will attract burrowing animals. Discarded Christmas trees can be stacked in clumps or along fencelines. Martin and Steele (in press) presented details of brush piles for various species of wildlife.

Logs and Slash

At least two logs per acre should be retained with bark intact as well as all the more deteriorated logs as wildlife habitat (Maser et al. 1979). Ideally, logs should be at least 20 feet long and 12 to 17 inches in diameter at the large end. Stable logs with one end in a stream should be maintained. To meet wildlife needs for logs, the following should be considered: species composition of the timber stand, diameter of the trees, density of the trees, number and decomposition classes of logs on ground, number and conditions of snags, and speed with which a new stand of trees can become established and reach a diameter of 13 to 17 inches (Maser et al. 1979).

Slash should be retained on 10 percent of clearcuts for cover. Where livestock grazing has priority, slash should be reduced to a depth of 8 inches on at least 75 percent of the area. Continuous concentrations of slash higher than 6 inches above ground or larger than 3 inches in diameter should be avoided to facilitate big-game and livestock travel. Chips should be scattered from wood chipping machines to a depth of less than 1 inch (Maser et al. 1979).

Snags and Live Den Trees

A mixture of snag species and diameters should be maintained for diversity. Taller snags are best (Raphael and White 1984). Silvicultural rotation times should be at least 100 years (150 years for pileated woodpeckers) (Conner 1978). Thinning unevenly throughout the stand will allow natural mortality of unthinned trees to occur, leaving snags. Snags will support insectivorous wildlife, helping to prevent insect populations from reaching epidemic levels (Beebe 1974). Individual snags or den trees should be evenly spaced. Windfirm trees with no evidence of root or butt rot should be selected for snags (Miller and Miller 1976). Clumps of snags and den trees are better than individual snags for withstanding windthrow and providing cover, but might increase inter- and intraspecific competition for dens (Titus 1983). Clumps should be 1/4 acre per 5 acres of regeneration cuts, which would provide 830 to 1,210 standing trees per 100 acres (Evans and Conner 1979).

Of the conifers in the Northwest, ponderosa pine, larch, and fir are used most often by woodpeckers and should be selected for snags

along with aspen, cottonwood, and willow. The density of snags needed for various species of woodpecker varies with the species (Table 4-20) and habitat (Table 4-21). In ponderosa pine, Thomas et al. (1979b) recommended 14 snags per 100 acres greater than or equal to 20 inches diameter at breast-height (d.b.h.), 136 snags per 100 acres greater than or equal to 12 inches, and 75 snags per 100 acres greater than or equal to 10 inches, for a total of 225 snags per 100 acres. Allowance must be made for loss of snags to logging operations, windthrow, and firewood, which typically is about 34 percent (Scott 1978). Firewood cutting should be limited to snags less than 15 inches d.b.h., with closure of certain logging roads to save high-value snags (McClelland et al. 1979). An uncut area of 20 times the stream width not exceeding 164 feet should be left on both sides of streams (Evans and Connor 1979). Where not enough snags exist, live trees can be frill-girdled and inoculated with sap rots. Trees also can be bored and inoculated with a suitable heart rot fungus at heights appropriate for woodpeckers (Conner et al. 1983). Snags also can be created with explosives (Bull et al. 1981).

Nesting Trees for Threatened and Endangered Species

The USDA Forest Service (Yoakum et al. 1980) uses the following procedures for managing nesting trees for threatened and endangered wildlife such as the red-cockaded woodpecker and bald eagle.

(1) Maintain an inventory of all nest sites and identifies in detail the location of each.

(2) Check nests periodically and record a cumulative history of nest use.

(3) Limit development activities within 5 chains of any nest tree to management measures beneficial to maintaining the nesting site.

(4) Establish and mark on the ground around each nest site a special buffer zone, 10 chains in radius.

(5) Within the buffer zone during the period from 1 November to 15 June, prohibit timber cutting, timber stand improvement, prescribed burning, road construction, recreation construction, and other intrusive activities.

(6) Evaluate critically all practices, such as insecticide spraying, aquatic plant control, and the use of fish toxicants, for their effects on nesting sites within the forest and areas outside of the forest but within 1/2 mile of the forest's boundary.

Table 4-20. Recommended numbers of snags to maintain selected densities of woodpecker populations in Northeastern United States.

Species	Probable optimum d.b.h. ranges of nest trees (in)	Optimum ranges of nest tree heights (ft)	Number of snags needed per 100 acres to maintain listed percentages of population maximums				
			Good		Fair		Poor
			100	80	60	40	20
Downy woodpecker	6-10	10-30	400	320	240	160	80
Hairy woodpecker	10-14	20-40	200	160	120	80	40
Pileated woodpecker	18-26	40-70	24	19	14	10	5
Common flicker	12-18	20-40	50[a]	40	30	20	10
Red-bellied woodpecker	14-22	30-50	270	220	160	110	55
Red-headed woodpecker	16-24	30-70	200[a]	160	120	80	40
			3,330[b]	2,660	2,000	1,330	670
Black-backed three-toed woodpecker	12-18	20-40	52	42	31	21	10
Northern three-toed woodpecker	12-16	20-40	52	42	31	21	10
Yellow-bellied sapsucker	10-14	20-40	100[a]	80	60	40	20

[a]Breeding season requirements.
[b]Winter habitat requirements.

Source: Evans and Conner 1979

Table 4-21. Density of snags by habitat.

Hard Snag Numbers Recommended For the Riparian Zone - Lakes and Rivers:

Snag Size (d.b.h. in)	Recommended Snags/100 Acres	Percent Maximum Population Level
20	15	100
12	94	70
10	53	70
6	105	70
Total	267	80

Hard Snag Numbers Recommended for the Riparian Zone - Ponds, Bogs, Streams:

Snag Size (d.b.h. in)	Recommended Snags/100 Acres	Percent Maximum Population Level
20	12	80
12	94	70
10	53	70
6	105	70
Total	264	75

Hard Snag Numbers Recommended for Douglas Fir-Ponderosa Pine, Grand Fir, Cedar, Hemlock, and Spruce Stands:

Snag Size (d.b.h. in)	Recommended Snags/100 Acres	Percent Maximum Population Level
20	11	70
12	67	50
10	38	50
Total	116	60

Hard Snag Numbers Recommended for Lodgepole Pine and Alpine Fir Stands:

Snag Size (d.b.h. in)	Recommended Snags/100 Acres	Percent Maximum Population Level
12	48	80
10	96	80
6	75	50
Total	219	60

Source: Godtel et al. (no date)

(7) Reserve 3 to 5 old-growth trees as roosting and potential nest trees within the buffer zone surrounding the nest. For red-cockaded woodpeckers, an aggregate of cavity-containing live pines, 10 to 25 inches d.b.h., 70 to 100 years old, is needed for each colony.

These special management considerations should stay in effect until it has been conclusively determined that the nesting site has been abandoned.

Augmenting Perches, Roosts, Nests, and Feeders

Perches and Roosts

Snags, dead limbs, firm treetops, fence posts, fence lines, utility poles, utility lines and the like, make good perches for birds. Snag management and maintenance of dead limbs in the forest will provide adequate perching sites for most birds. However, in open areas, thoughtful augmentation and improvement of existing structures can increase available perches and roosts.

In open rangeland, raptors use electric poles as perches, and many are electrocuted. An estimated 95 percent of such mortality can be prevented by correcting 2 percent of the electric poles (Figure 4-36). Many power-line designs and corrective measures exist (U.S. Rural Electrification Administration 1972, Avery 1978, Raptor Research Foundation, Inc., no date). Artificial perches for hawks and owls can be built on telephone poles, metal poles, or trees stripped of branches, 20 to 50 feet tall, planted at least 3 feet deep, and spaced 1/25 acres for raptors (Herricks et al. 1982). Brush piles provide suitable perches for smaller birds.

Many species of birds prefer conifers for roosting. For example, in uplands, turkeys prefer open-limbed pines of 10 to 20 inches d.b.h. with a clean bole for the first 20 to 30 feet and branches at least 2 to 4 inches in diameter. In bottomland in the South, they prefer to roost over water in cypress or hardwoods. Preserve known roosting trees as well as thickets of conifers for species like turkeys, blue grouse, and ruffed grouse.

Preserve scattered stands of tall, vigorous sagebrush for sage grouse. Where sparse, evergreen and deciduous trees and shrubs should be maintained 5 to 30 feet high for California quail (Emlen and Glading 1945) and 7 to 17 feet high for Gambel's quail (Goodwin and Hungerford 1977). Protective roosting sites for California quail can be made by cutting limbs of large trees above the primary forks and piling them in the forks. This causes the tree to bush out, creating good nesting cover for doves and roosting cover for quail (Bauer 1963). Thickly foliated trees or shrubs such as junipers and live oaks should be planted as permanent roosting habitat for California and Gambel's quail (Leopold 1977). Until trees and shrubs are large enough, elevated brush piles can be constructed. Roosts should be spaced about one every 30 to 40 acres within

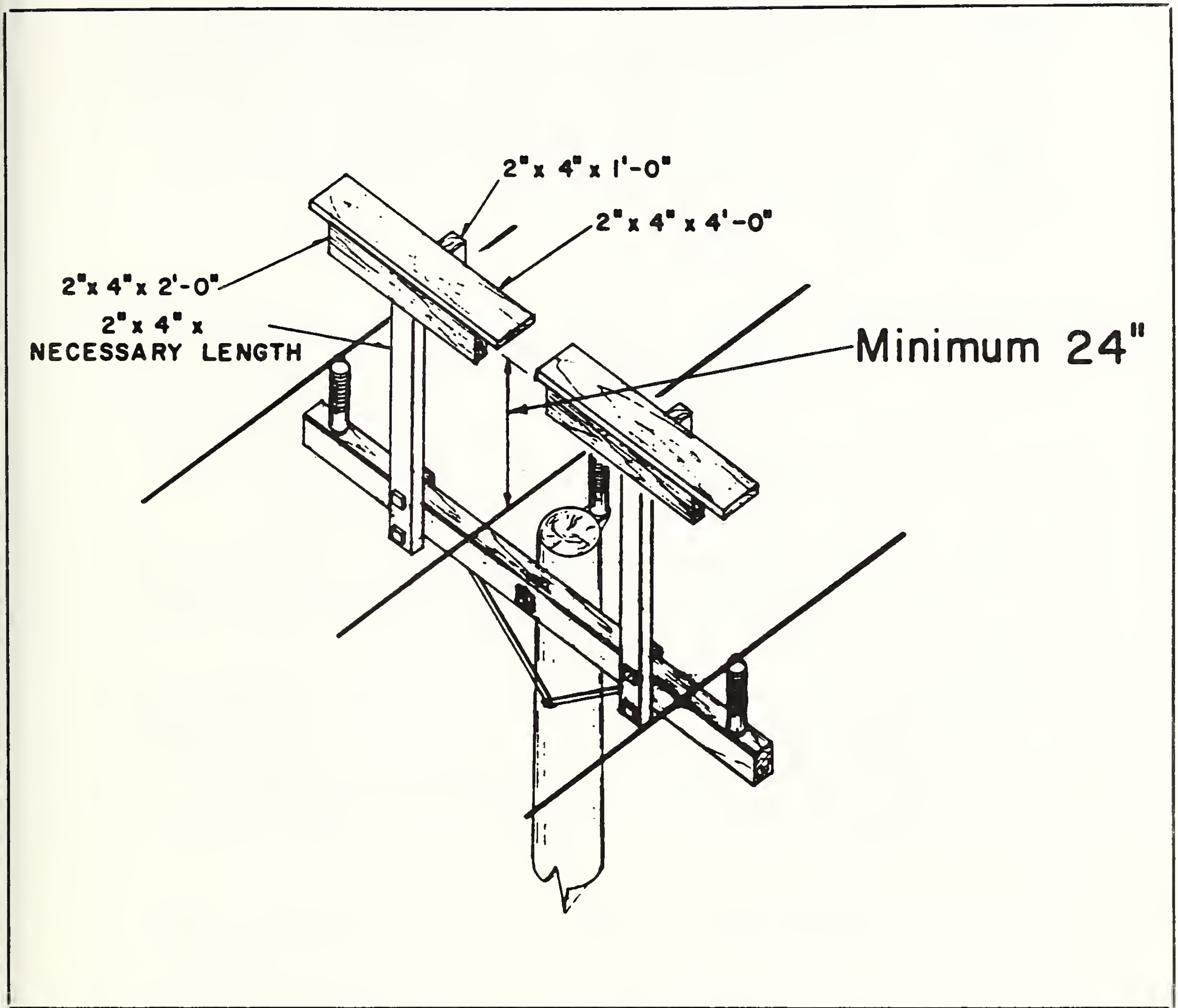


Figure 4-36. Plans for perches on power lines to help reduce cases of raptor electrocutions.

Source: Nelson and Nelson 1976

50 feet of brushy cover (Emlen and Glading 1945) and within 1/2 mile of open water (MacGregor 1950).

If trees used by eagles blow down, an artificial perch can be installed that has three 60-foot poles placed in a tepee formation with three 20- to 30-foot cross perch poles. Fast-growing poplars, elms, and willows should be planted around the base of the artificial tree to replace it in time (Oregon State Game Commission 1972). In open prairies or rangeland, trees should be planted at intervals, especially near water, to provide perching and nesting sites for raptors.

Artificial Nests

Artificial nests (Figure 4-37) may be used to temporarily alleviate local inadequacies in snag, den, and nest tree management. However, they are not an entirely suitable substitute because they may only partially provide one of the 40 uses of snags listed by Davis (1983), may be death traps in winter, may be sources for predators that learn to search for nest boxes, have high maintenance costs, and may lead to blowfly parasitism because of their shape (Miller and Miller 1980). They also may be visually unattractive.

Birdhouses. Birdhouses take many designs, with dimensions as varying as those of bird species (Table 4-22). They should be built of durable wood like cypress, pine, redwood, cedar, and yellow poplar. Some birds require bark-covered nest boxes.

Deermice Boxes. Insects may be controlled not only by insectivorous birds and bats (Yoakum et al. 1980) but also by deermice preying on larvae and pupae of gypsy moths in young, even-aged hardwood stands (Smith 1975). Deermice also furnish an increased prey base for various predators. Nest boxes for deermice are 5-inch cubes of 3/8-inch exterior plywood with a hinged lid and a 1-inch entrance hole (Nicholson 1941).

Gray Squirrel Nest Boxes. Place nest boxes for gray squirrels and other wildlife species (Figure 4-38) on the east side of the tree (Carey and Gill 1983) in 2 to 3 per acre densities. Nest boxes should be placed in areas producing at least 100 pounds per acre of mast, preferably in hardwood stands 30 to 60 years old, when cavities for squirrels are scarce but mast crops are abundant (Yoakum et al. 1980). The entrance, lined with sheet metal to prevent gnawing, can be made smaller for flying squirrels.

Mourning Doves Cones. Place nesting cones (Figure 4-39) for mourning doves 6 to 16 feet above ground.

Raptor Nest Baskets and Platforms. Some raptors will use chicken wire nest baskets. Others nest on platforms (Figure 4-40). Osprey platforms 24 inches in diameter may be attached to erected cedar poles 25 feet high and 1 to 5 feet in diameter (Kahl 1972). They

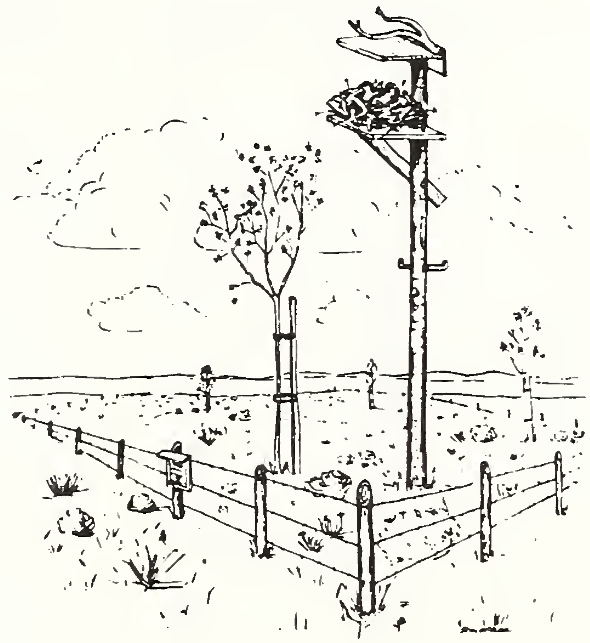


Figure 4-37. Artificial nest structure for raptors.

Source: Modified from Olendorff and Stoddart 1974 in Yoakum et al. 1980

Table 4-22. Dimensions of nesting boxes for various bird species and their recommended above-ground height.

Species	Floor of Cavity (inches)	Depth of Cavity (inches)	Entrance above Floor (inches)	Diameter of Entrance (inches)	Height above Ground[a] (feet)
Bluebird	5x5	8	6	1-1/2	5-10
Robin	6x8	8	(b)	(b)	6-15
Chickadee	4x4	8-10	6-8	1-1/8	6-15
Titmouse	4x4	8-10	6-8	1-1/4	6-15
Nuthatch	4x4	8-10	6-8	1-1/4	12-20
House wren	4x4	6-8	1-6	1 - 1-1/4	6-10
Bewick's wren	4x4	6-8	1-6	1 - 1-1/4	6-10
Carolina wren	4x4	6-8	1-6	1-1/2	6-10
Violet-green swallow	5x5	6	1-5	1-1/2	10-15
Tree swallow	5x5	6	1-5	1-1/2	10-15
Barn swallow	6x6	6	(b)	(b)	8-12
Purple martin	6x6	6	1	2-1/2	15-20
Prothonotary warbler	6x6	6	4	1-1/2	2-4
Phoebe	6x6	6	(b)	(b)	8-12
Crested flycatcher	6x6	8-10	6-8	2	8-20
Flicker	7x7	16-18	14-16	2-1/2	6-20
Golden-fronted woodpecker	6x6	12-15	9-12	2	12-20
Red-headed woodpecker	6x6	12-15	9-12	2	12-20
Downy woodpecker	4x4	9-12	6-8	1-1/4	6-20
Hairy woodpecker	6x6	12-15	9-12	1-1/2	12-20
Screech owl	8x8	12-15	9-12	3	10-30
Saw-whet owl	6x6	10-12	8-10	2-1/2	12-20
Barn owl	10x18	15-18	4	6	12-18
Sparrow hawk	8x8	12-15	9-12	3	10-30
Wood duck	10x18	10-24	12-16	4	10-20

[a]Many experiments show that boxes at moderate heights mostly within reach of a man on the ground are readily accepted by many birds.

[b]One or more sides open.

Source: Kalmbach et al. 1969

also may be attached to trees topped by chainsaw or primacord (200 grains), which is less hazardous than using chainsaws. The Intermountain Region of the USDA Forest Service reports that the primacord should be tightly wrapped just a few inches above a full whorl of limbs that will provide support for nest construction. The cap wire is attached to the primacord and to a lower limb with a slip knot and dropped to the ground. The charge is detonated electronically at a safe distance (at least one chain) from the

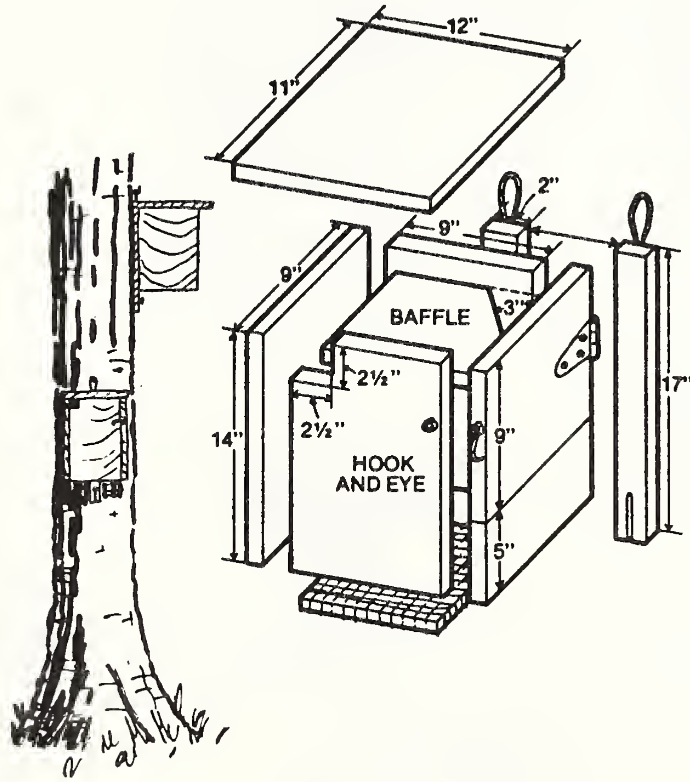


Figure 4-38. Squirrel nest box. (Wooden bottoms result in higher use than wire-mesh bottoms. The shelf baffle, just below entrance height with a second entrance in the far corner, makes the box more resistant to predators, allows the box to be smaller, provides a protected resting spot for squirrels, and probably helps prevent heat loss; access to the box interior is through the side, making it easier to inspect and clean the box and to capture animals using the box. If the box is to be used primarily to capture animals, the shelf should be hinged or narrowed to 3 inches to make it easier to remove animals.)

Source: Carey and Gill 1983

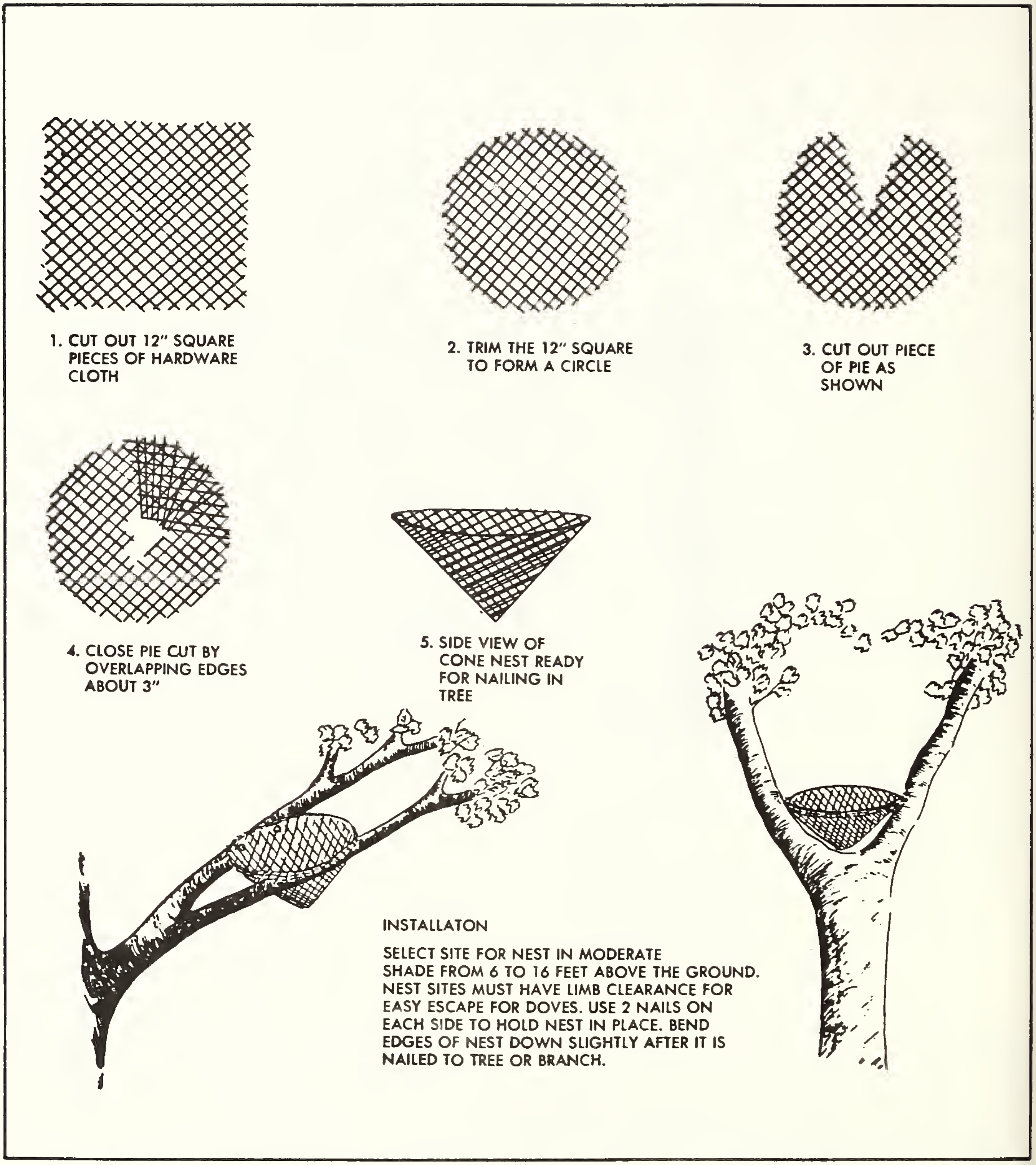


Figure 4-39. Wire nest cones for mourning doves.

Source: Cowan 1959

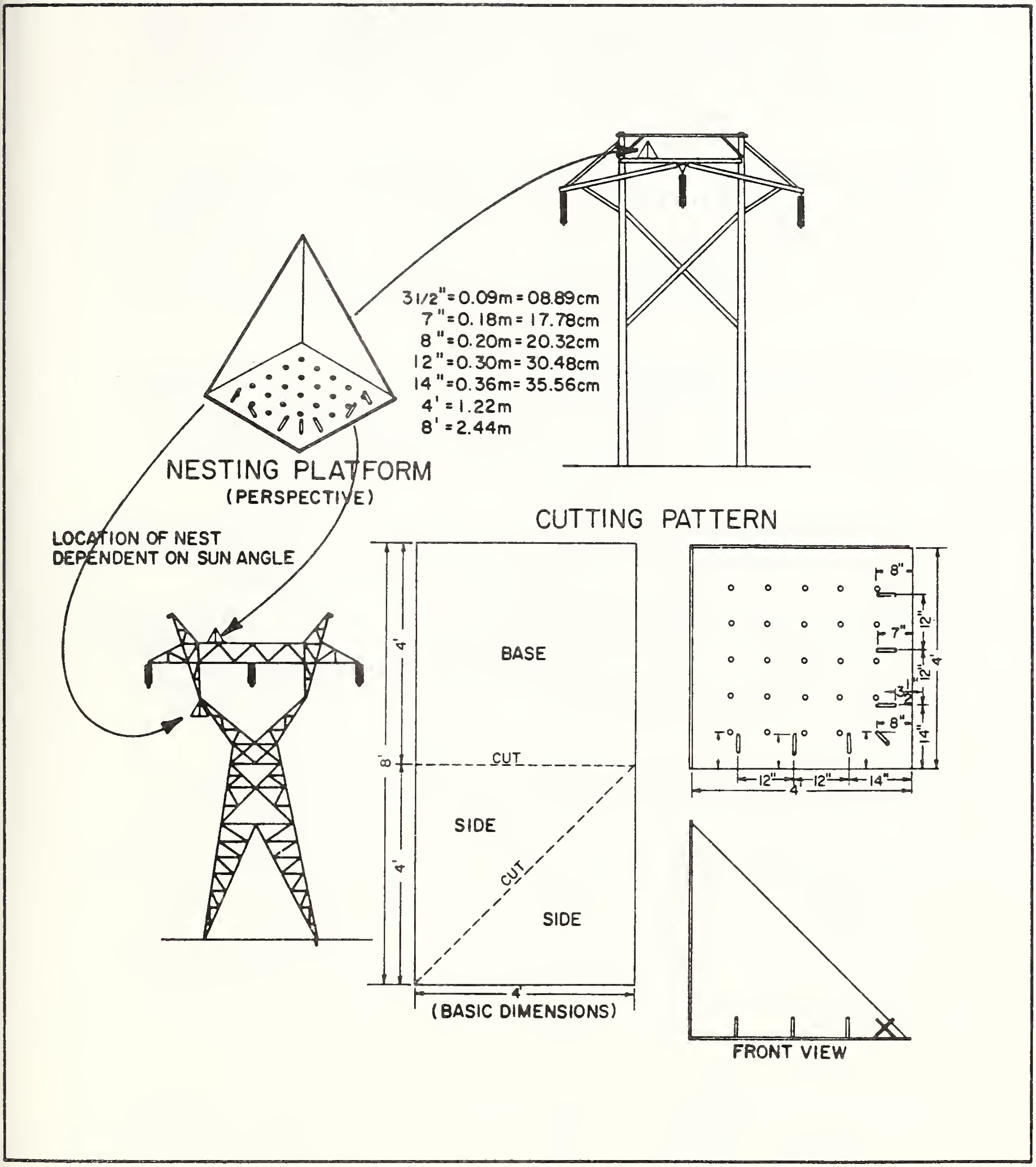


Figure 4-40. Eagle nesting platforms.

Source: Nelson and Nelson 1976

tree. The cap wire is then pulled from the tree. The number of wraps is experimental but guidelines are as follows: seven wraps for a 10-inch diameter tree, five for a 6-inch tree, and four for a 4-inch tree, or about one wrap per 1 inch. Raptor nest platforms can be placed on powerlines.

Nesting Platforms for Phoebes and Barn Swallows. Nesting platforms for phoebes and barn swallows can be provided in culverts and bridges (Figure 4-41). Design features for concrete bridges that can enhance their potential as wildlife habitat include expanded beams for nest construction, crevices in which bats can roost and rear young, roughened concrete to aid nest construction by some species of birds, wooden planks to create platforms on which birds can nest, and bird boxes for use by a variety of birds.

Creating Cavities with Chainsaws. Chainsaws can be used to create a cavity in a tree (Figure 4-42) in about 8 minutes, but the chainsaw must be modified with an 8-inch bar with a low-profile, anti-kick chain ("chisel chain") and kickback guard (Carey and Gill 1983).

Burrows for Burrowing Owls. For burrowing owls, artificial burrows should be buried 6 inches in the nest chamber for thermal stability (Collins and Landry 1977). The chamber is 12 by 12 by 8 inches deep with a 4 by 4-inch tunnel connecting it to the burrow entrance. The tunnel is about 6 feet long with a right-angle turn about 4 feet from the entrance to maintain darkness in the chamber. chamber. Warp-resistant exterior plywood should be used with natural dirt base for sides and top of the nest chamber and tunnel (Collins and Landry 1977).

Artificial Burrows for Small Mammals. Species such as rabbits, opossums, skunks, and woodchucks can be attracted to artificial burrows that are 18 by 18 by 12 inches, made of durable 3/4-inch wood, buried at ground level, and that have a removable top, a dirt floor, and two entranceways of three or four 5- or 6-inch field tiles buried at a 45° angle (Figure 4-43) Herricks et al. (1982). Two snug semicircles should be cut on opposite ends at the bottom of the box to fit the tile, and the top of the box should be covered with brush. The burrows should be constructed in well-drained areas near good cover (Russell no date). Tunnels with 90° turns to increase darkness are better. The entire unit should be built of warp-resistant plywood. Herricks et al. (1982)

Cliff-nesting Raptors. For cliff-nesting raptors, the cavity should be constructed at least halfway to the cliff top. The size varies with the species of raptor (Call 1979). For golden eagles, nest cavities or ledges should be at least 6 feet long, 4 feet deep, and 4 to 6 feet high. For prairie falcons, the cliff face height should be at least 20 feet, and the artificial nest hole or ledge at least 12 inches deep by 24 inches long by 12 inches high (Fyfe and Armbruster 1977).

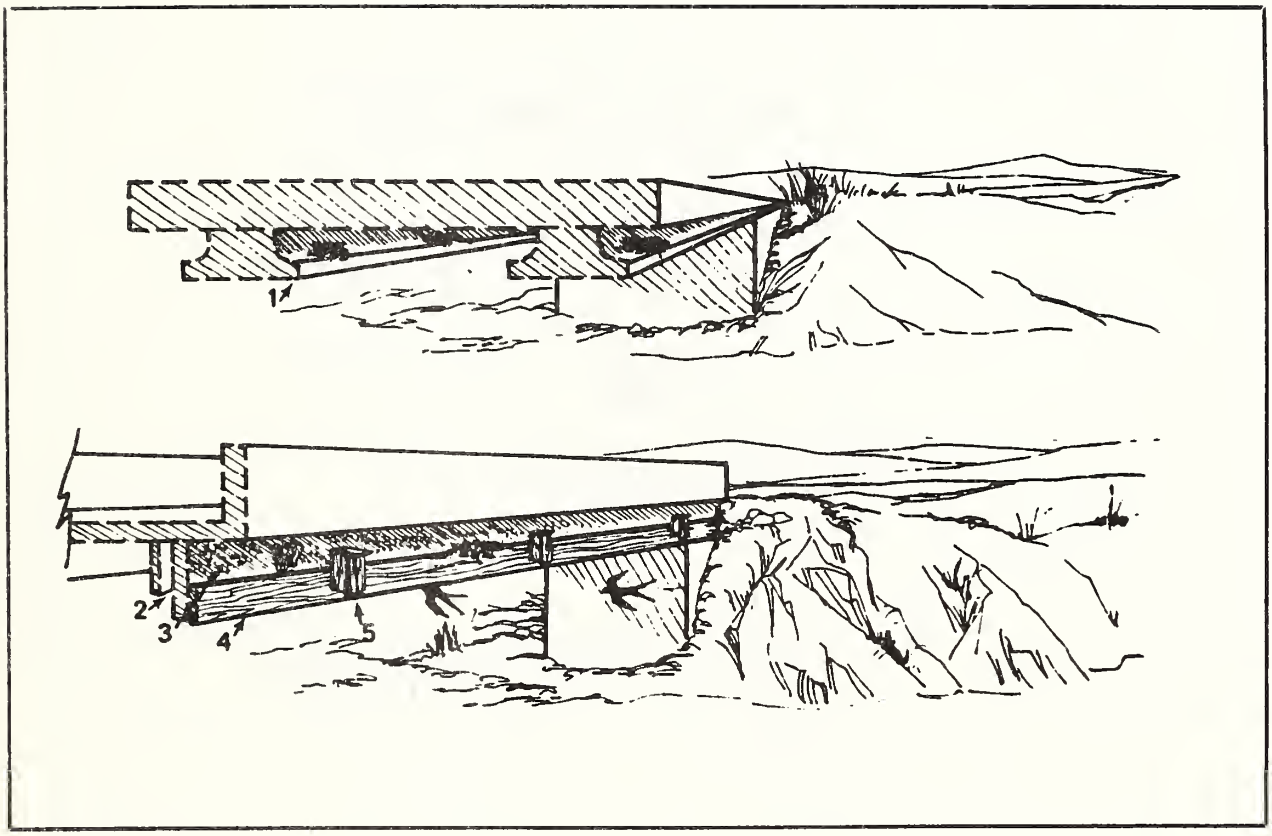


Figure 4-41. Improvement to concrete bridges.

Source: Maser et al. 1979

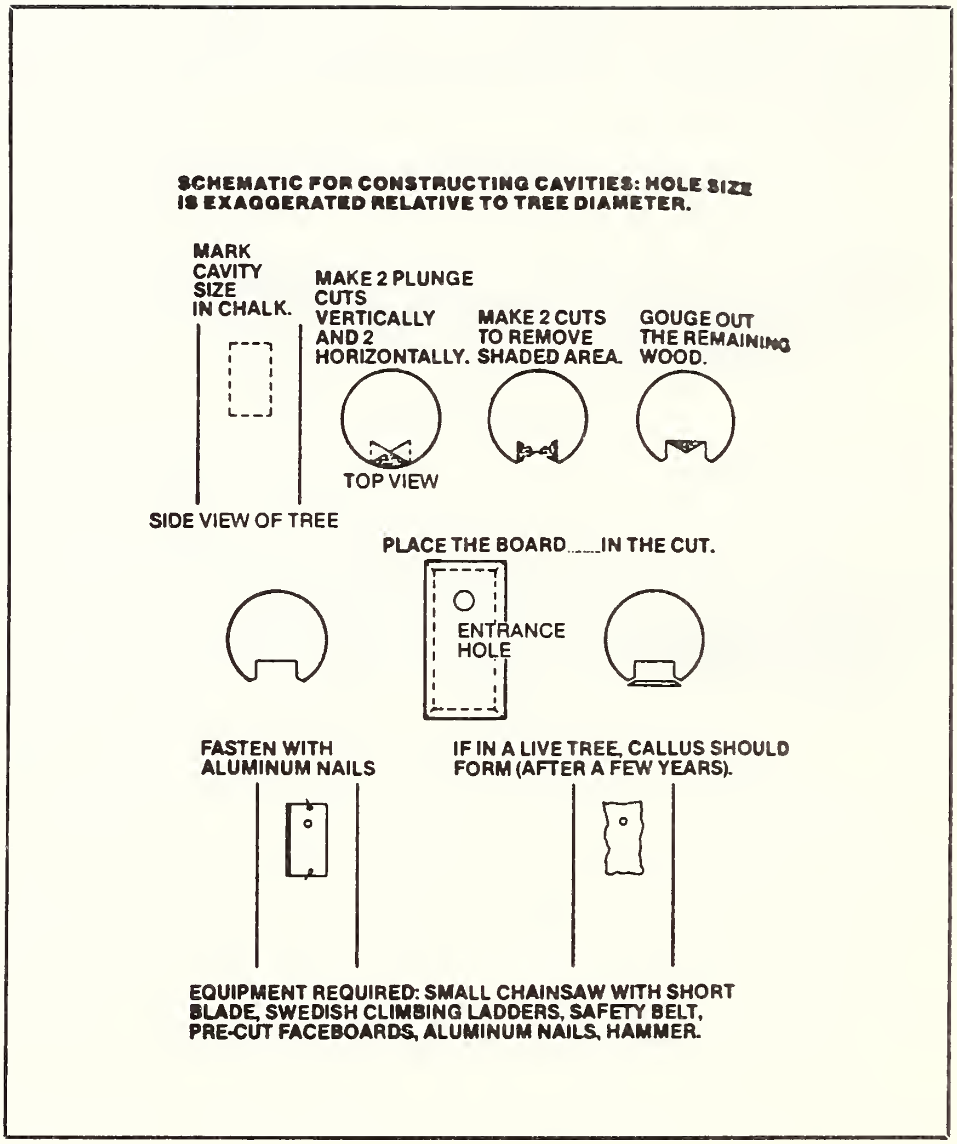


Figure 4-42. Constructing cavities with a chain saw.

Source: Carey and Gill 1983

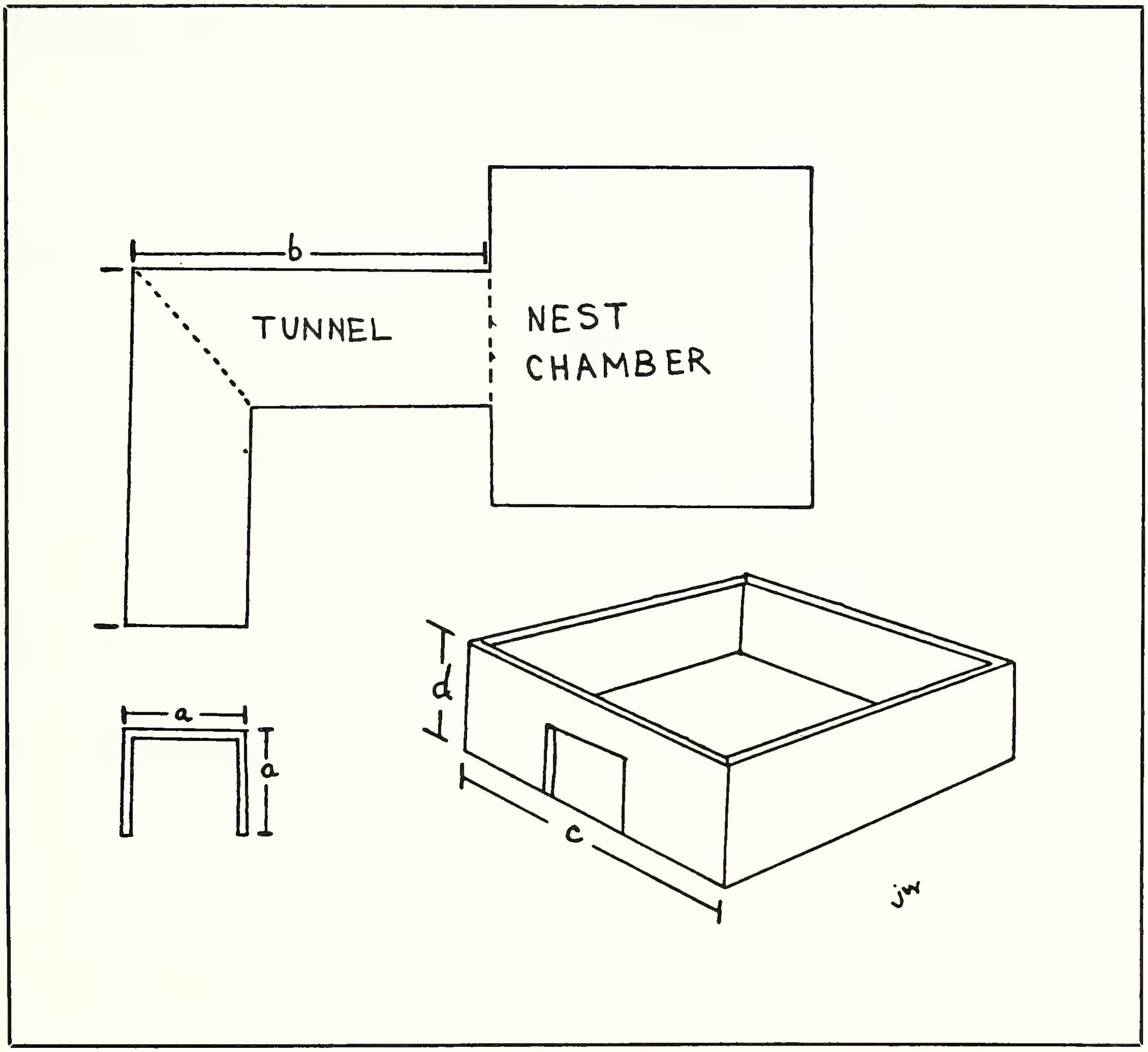


Figure 4-43. Artificial burrow construction.

Source: Herricks et al. 1982

Feeders. Feeders can be used to attract wildlife for observation or for emergency winter feeding. Figures 4-44 to 4-49 (unpublished figure, Pennsylvania Game Commission) illustrate feeders for deer, turkey, grouse, pheasant, quail, squirrel, and other wildlife. Feeders should be located in areas used by wildlife, protected from wind, and near cover (because they often attract predators). Once begun, feeding must continue through food shortages or critical weather.

Fences, Passes, and Exclosures

Thorough descriptions and illustrations of the various types of fences, passes, and exclosures, especially for pronghorns and deer, were presented by Seamans (1951), Longhurst et al. (1962), Spillet et al. (1967), the USDA Forest Service (1972) Structural Range Improvement Handbook, the U.S. Bureau of Land Management (1974) Proceedings Regional Fencing Workshop, and the U.S. Bureau of Land Management (1975) Manual 1737 - Fencing. Chapter 20 ("Habitat Improvement Techniques") by Yoakum et al. (1980) in the Wildlife Management Techniques Manual (Schemnitz 1980) provides a discussion, with supporting references and well-illustrated specifications, of net or woven fences, barbed-wire fences, upright fences, over-hanging or slanting fences, electric fences, interstate highway fences, study exclosures, underpasses and overpasses, gates, cattle guards, and antelope passes.

Snowfences reduce snow depths in shrub stands, facilitating deer use and creating drifts deep enough to protect overused and newly seeded areas (Regelin et al. 1977). A slanting deer fence (Figure 4-50) effectively and cheaply excludes deer. The Cooperative Extension Service at Pennsylvania State University developed a 5-strand, high-tensile 12-1/2-gauge steel wire fence electrified by a high-voltage, low-impedence, New Zealand-style energizer. The bottom wire is 10 inches off the ground; the other wires are 12 inches apart. Hollows should be filled, humps graded, and brush removed from the fence line. An open strip 6 to 8 feet outside the fence should be maintained so that deer will walk toward fence and not jump brush and fence alike. Temporary flagging should be attached to any new fence.

Figure 4-51 provides specifications for constructing barbed-wire fences that will contain sheep and cattle but allow deer and antelope to pass. Figure 4-52 provides specifications for fences that contain cattle and allow deer to pass. When livestock are not present, raising or lowering one or more wires can be the most successful and efficient fence modification for passage of big game (Figure 4-53).

WATER DEVELOPMENT

The U.S. Soil Conservation Service, for most States, and the State wildlife agencies provide descriptions of wildlife watering facilities. The USDA Forest Service (1972) Structural Range Improvement Handbook provides 38 pages of description and 48 pages of figures about watering facilities for livestock in Chapter 40 (Range Water

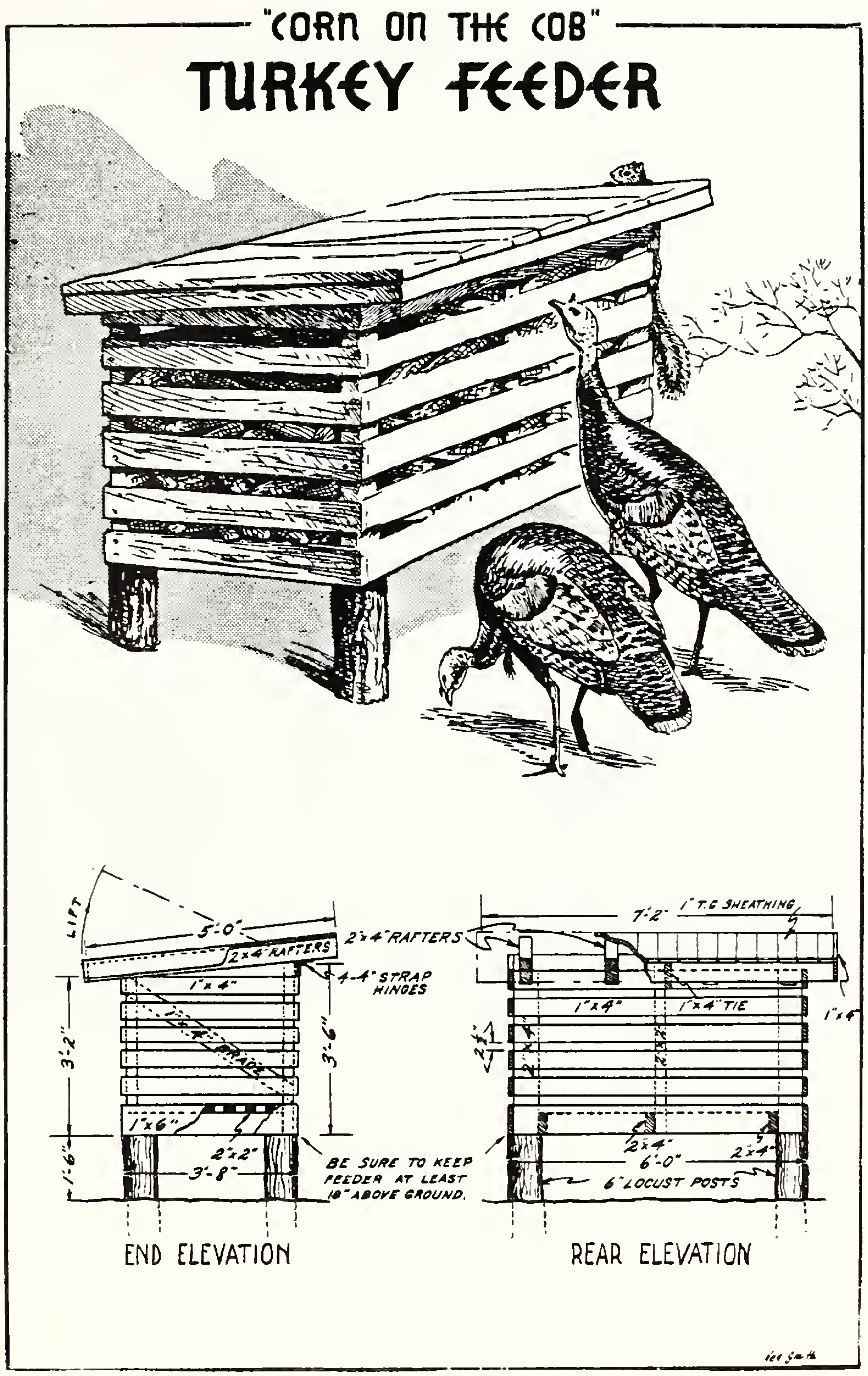


Figure 4-44. "Corn on the cob" turkey feeder.

Source: Unpublished figure, Pennsylvania Game Commission

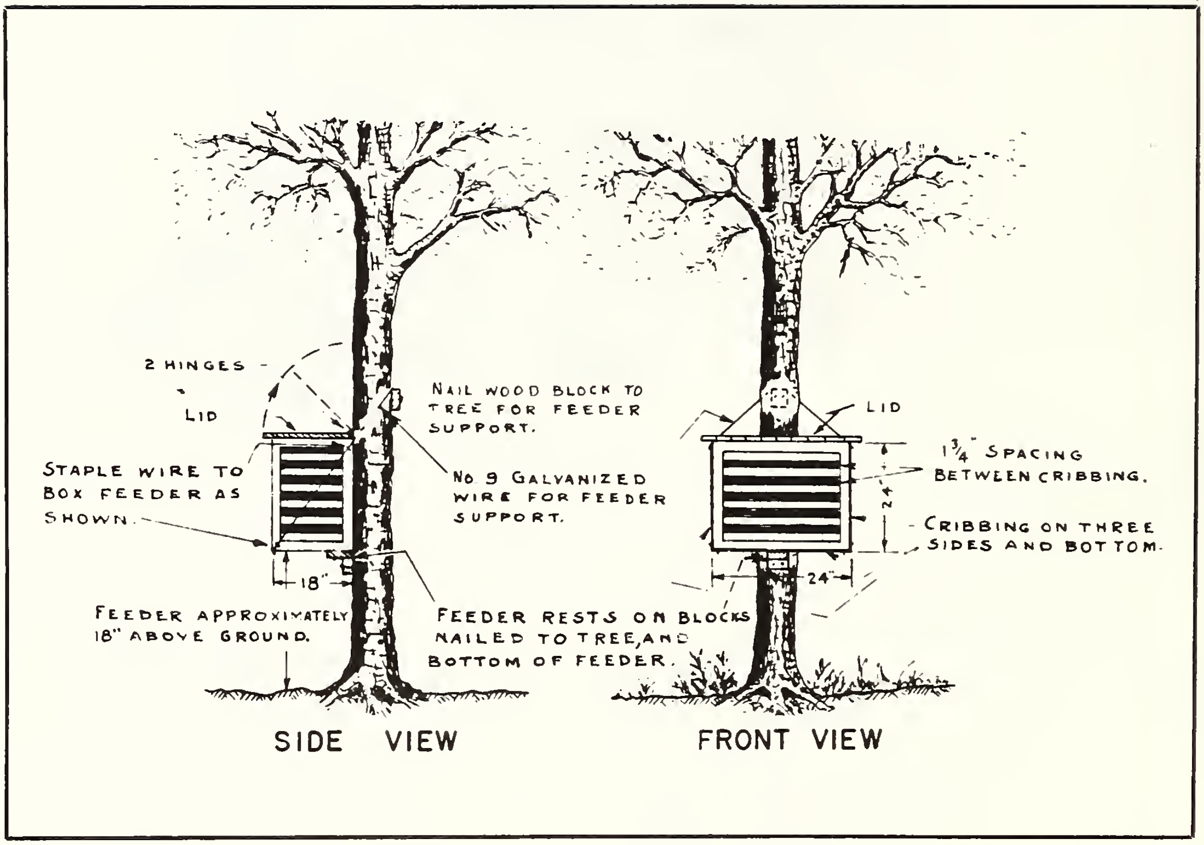


Figure 4-45. Small box turkey feeder.

Source: Unpublished figure, Pennsylvania Game Commission

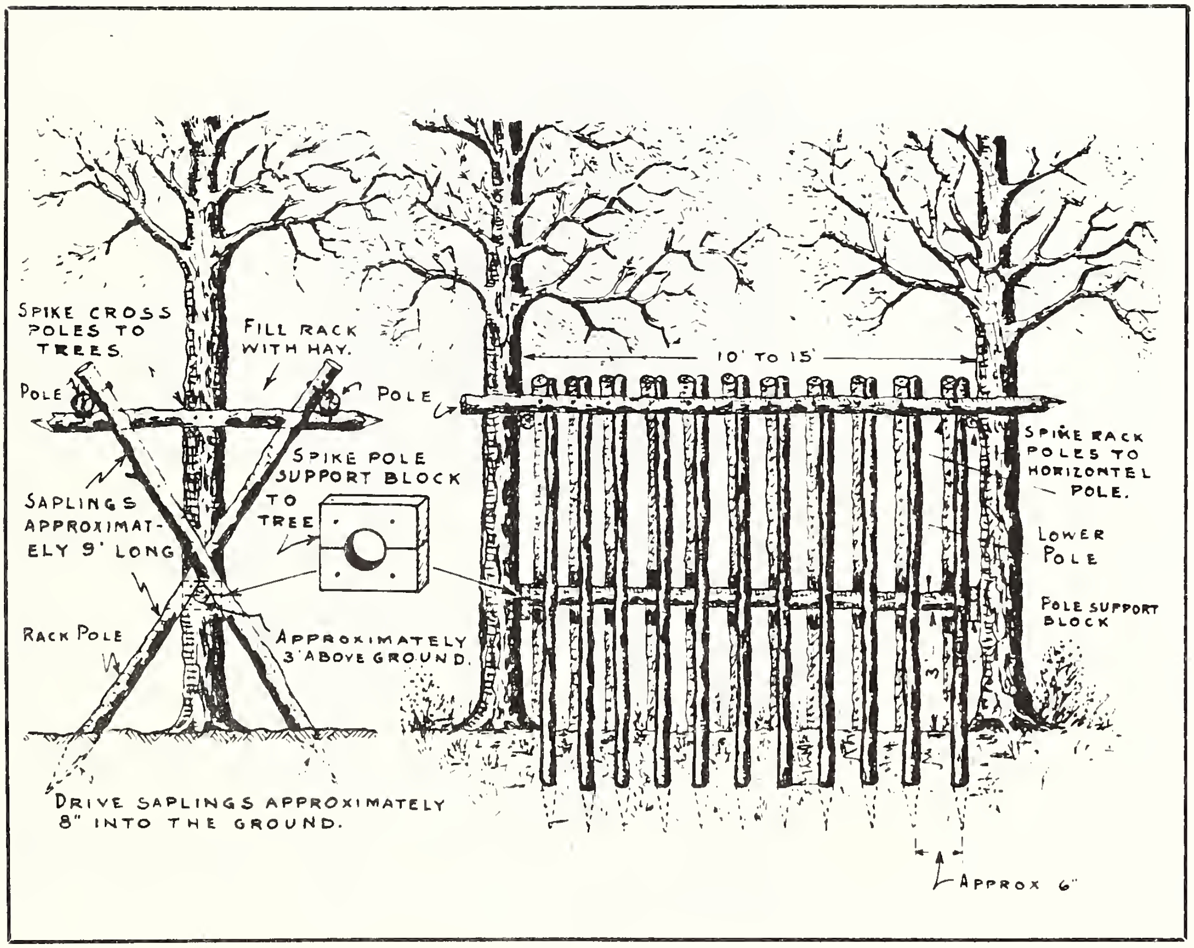


Figure 4-46. Hay rack deer feeder.

Source: Unpublished figure, Pennsylvania Game Commission

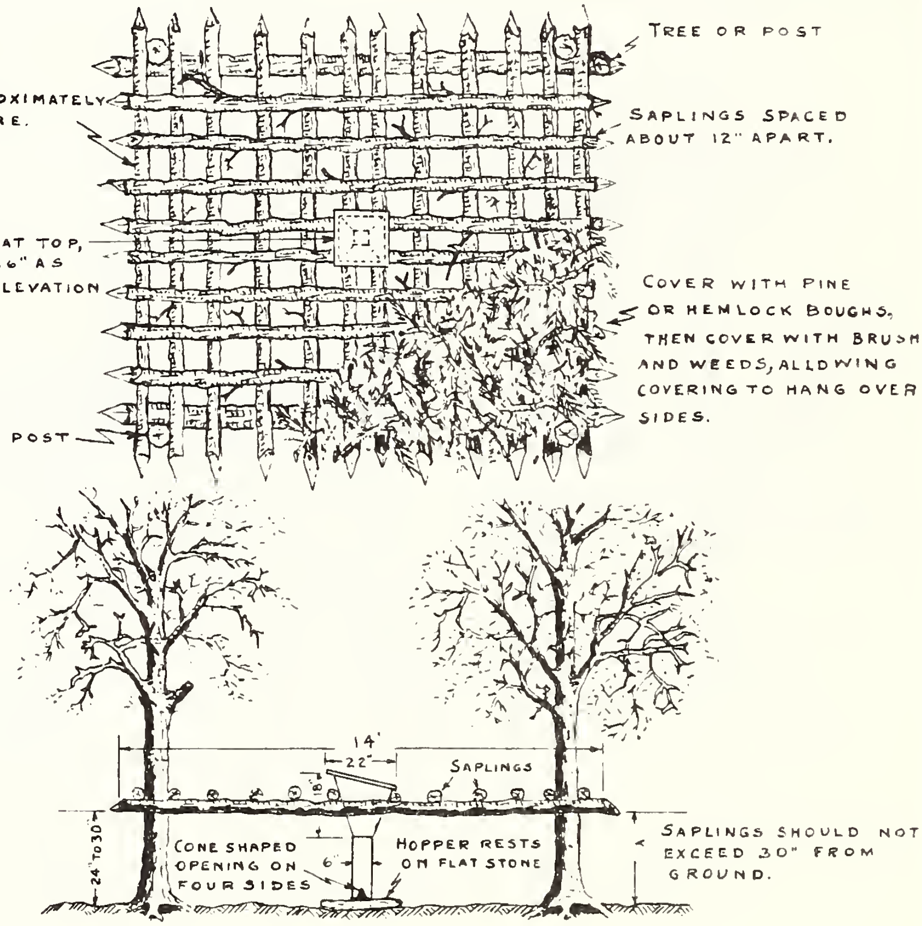


Figure 4-47. Hopper shelter and feeder.

Source: Unpublished figure, Pennsylvania Game Commission

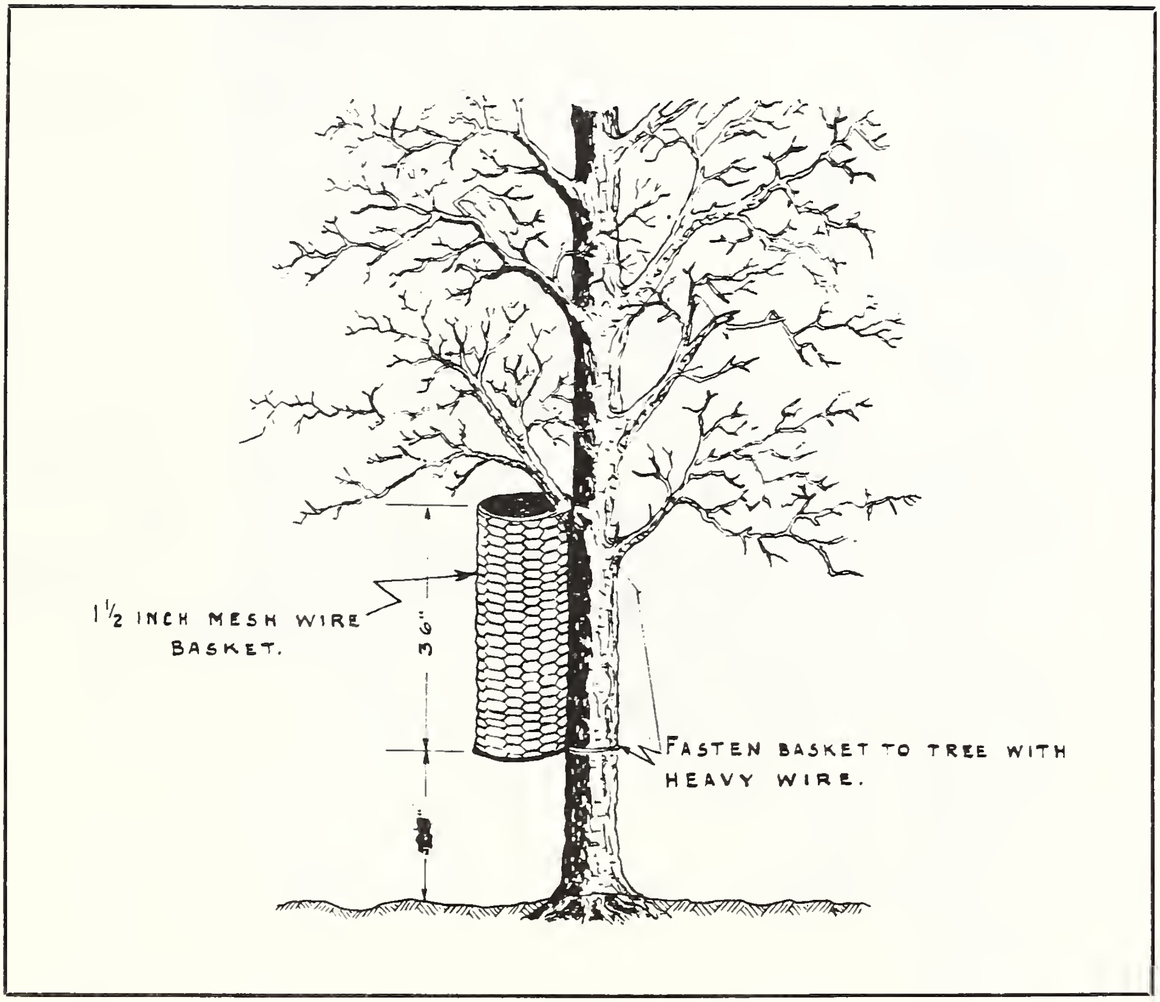


Figure 4-48. Wire basket feeder.

Source: Unpublished figure, Pennsylvania Game Commission

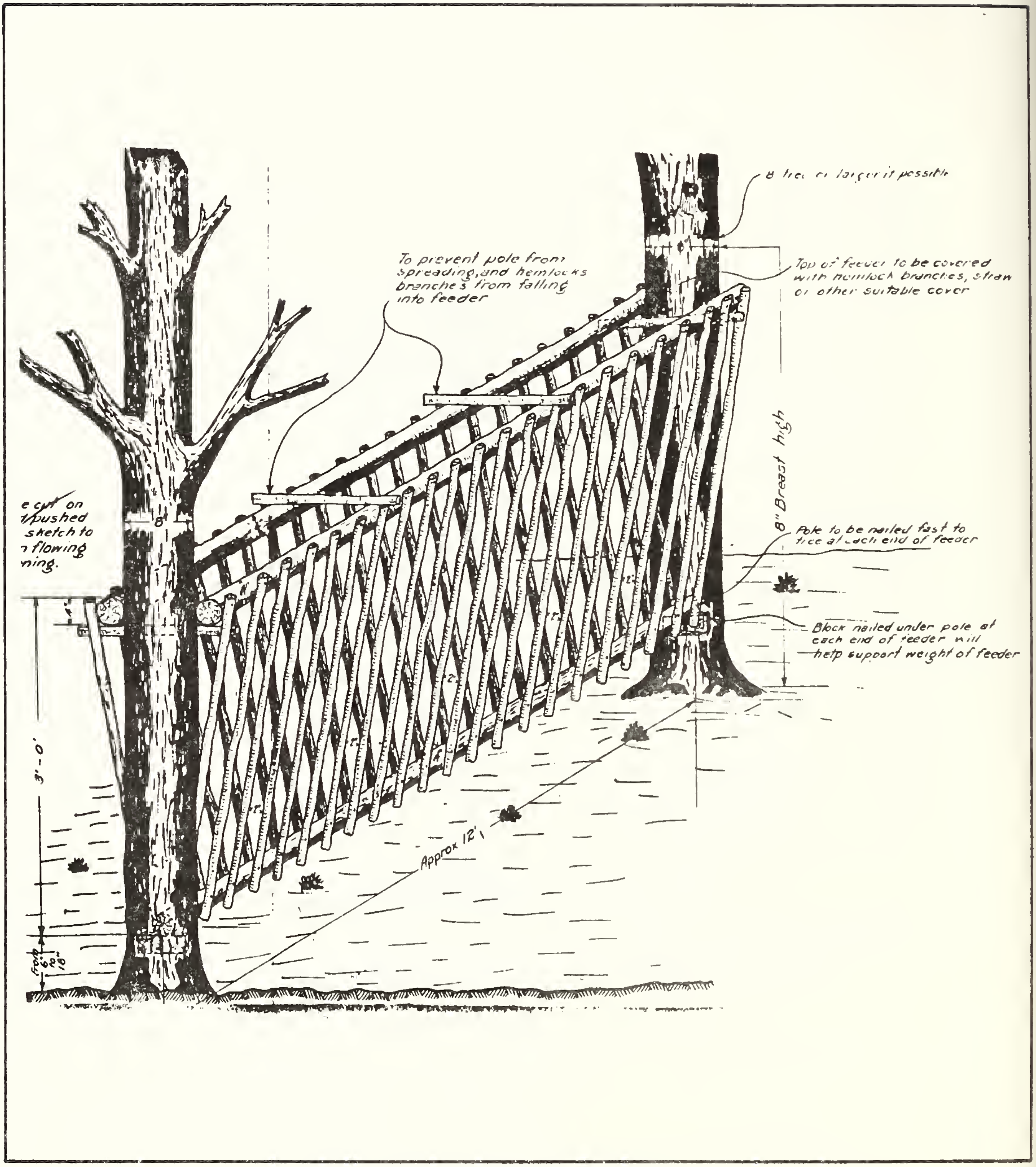


Figure 4-49. Wildlife feeder.

Source: Unpublished figure, Pennsylvania Game Commission

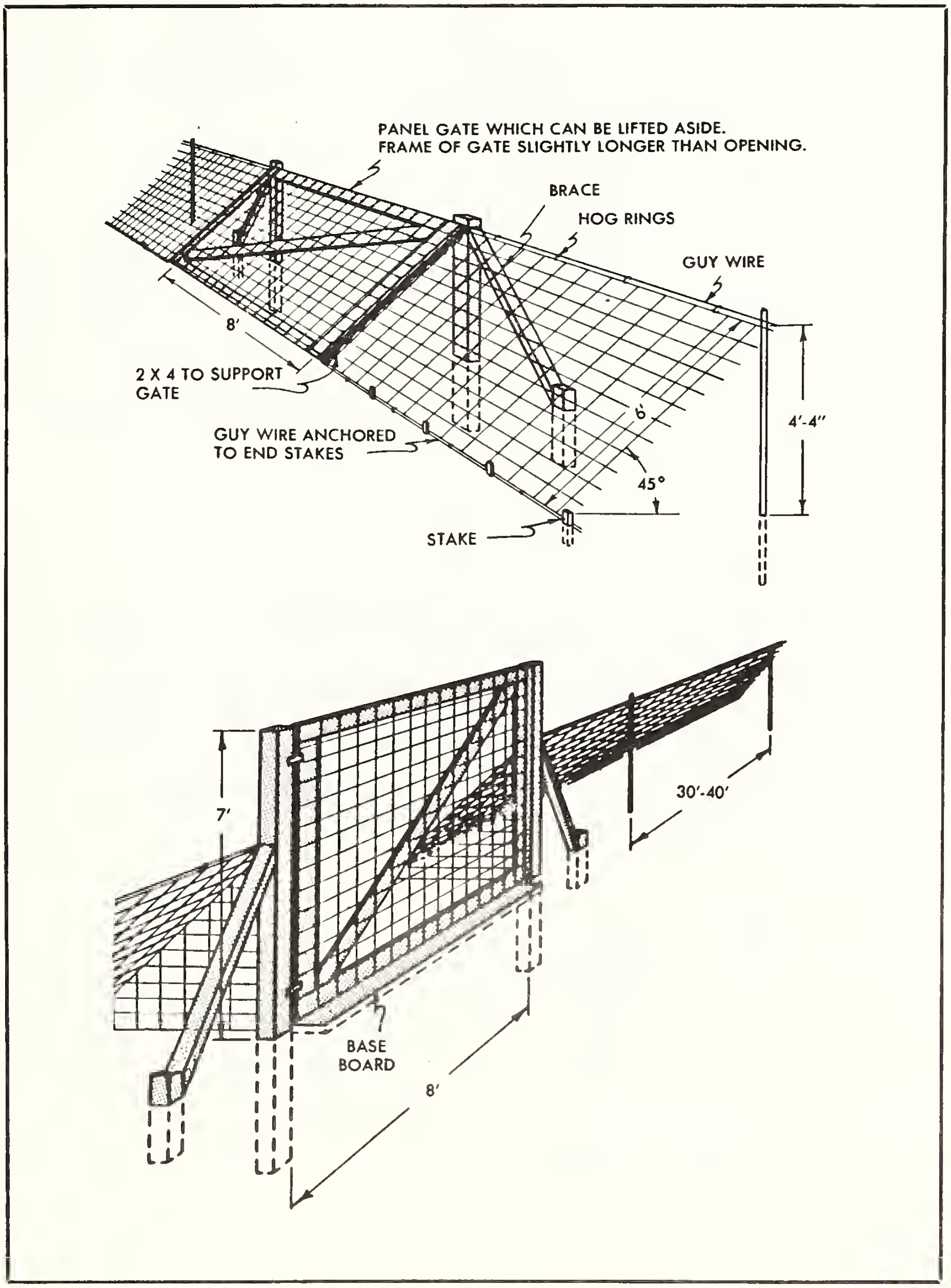


Figure 4-50. Typical slanting deer fence with examples of vertical or slanting gates.

Source: Longhurst et al. 1962 in Yoakum et al. 1980

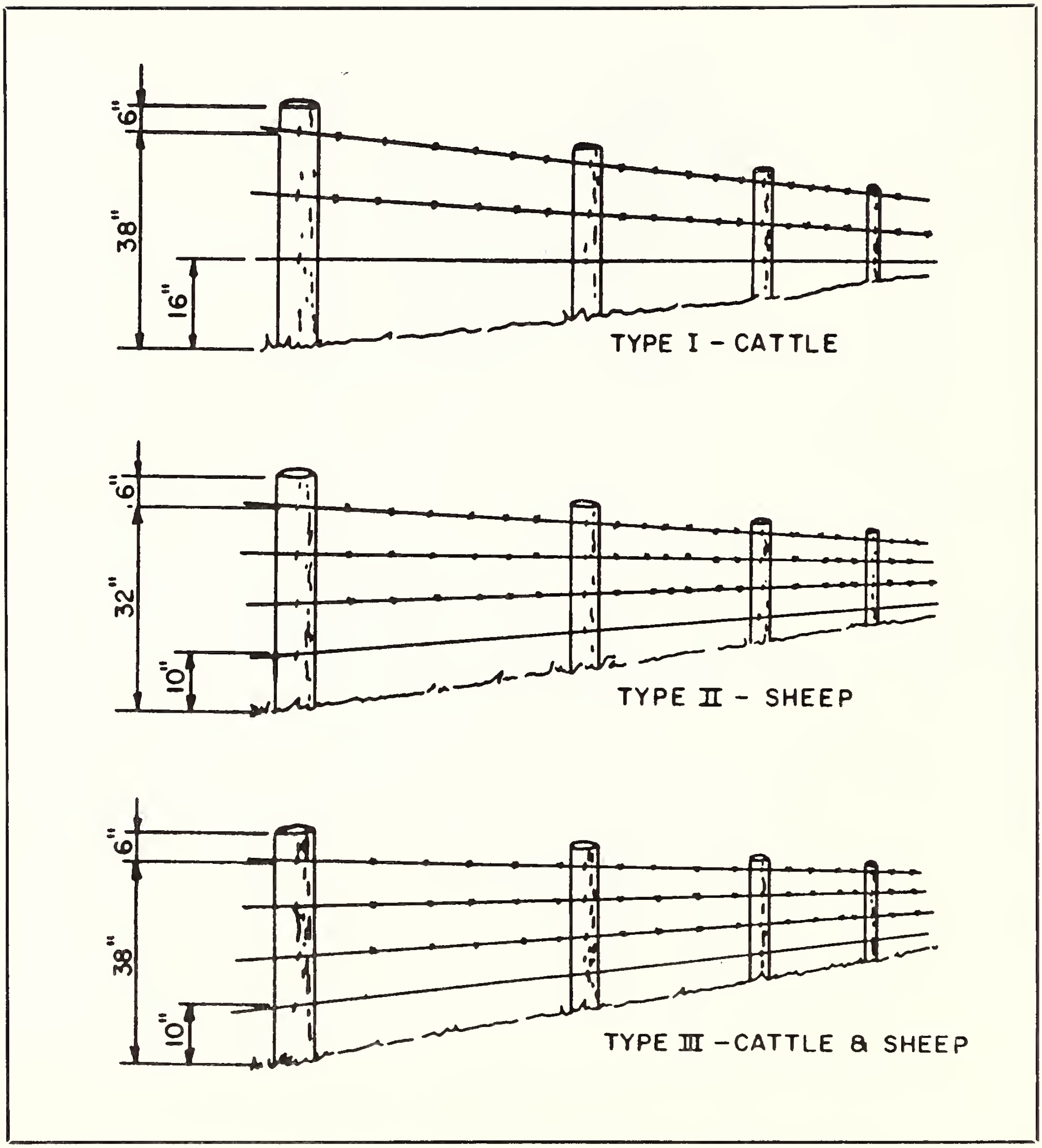


Figure 4-51. Fences constructed for sheep and cattle control with deer access.

Source: U.S. Bureau of Land Management 1974 in Yoakum et al. 1980

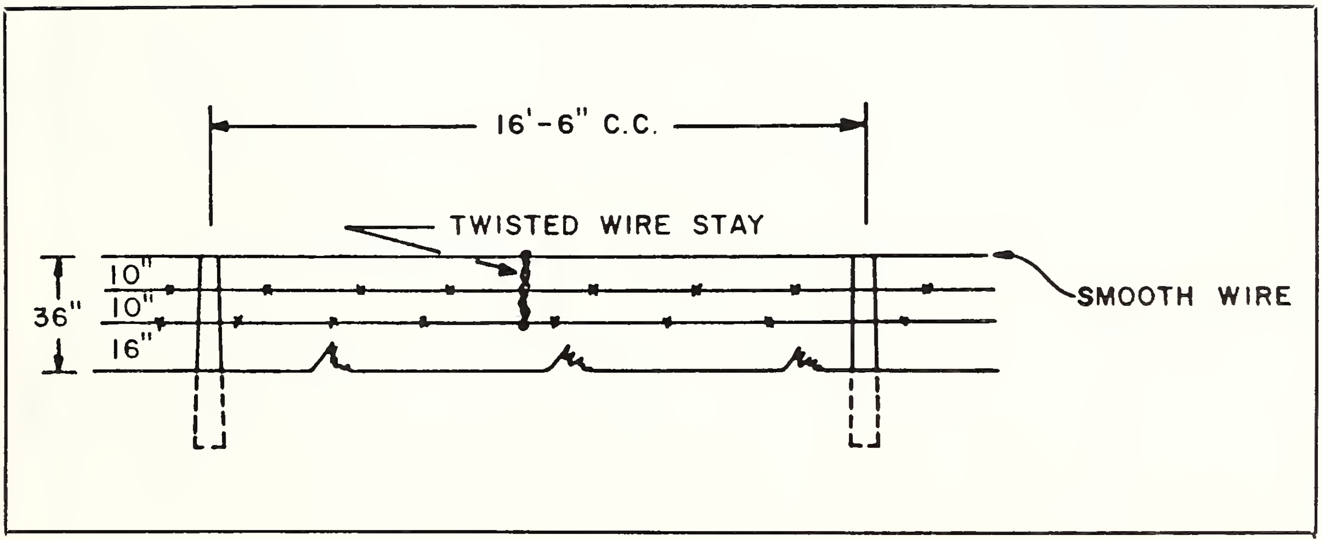


Figure 4-52. Fence constructed for cattle control with deer access.

Source: Yoakum et al. 1980

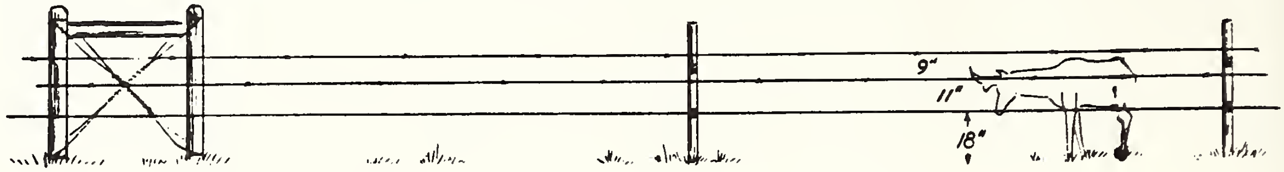


Figure 1a. Standard configuration.

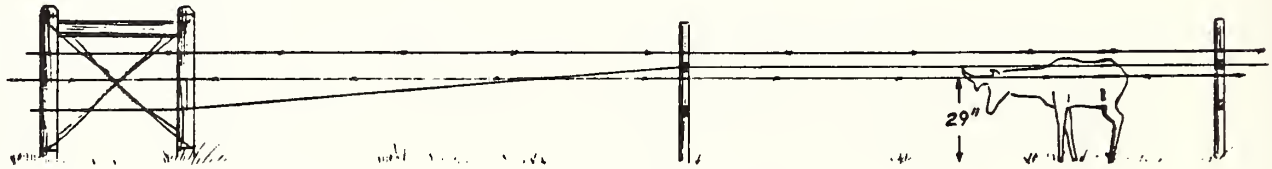


Figure 1b. Modification facilitating movement under most conditions.

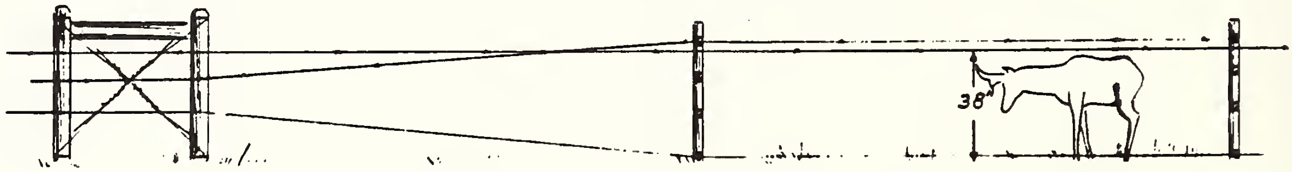


Figure 1c. Adjustment allowing almost total freedom of movement.

Three-strand, 38-inch antelope fence modification

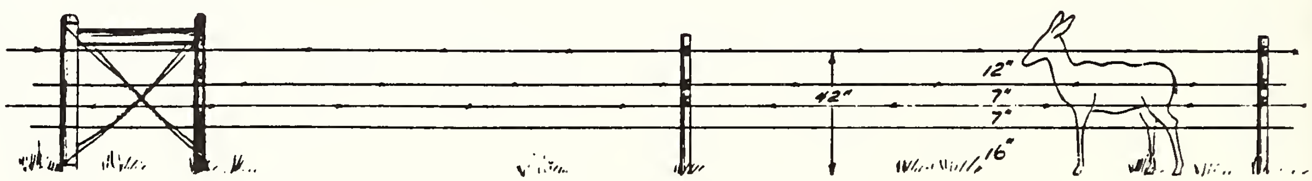


Figure 2a. Standard configuration.

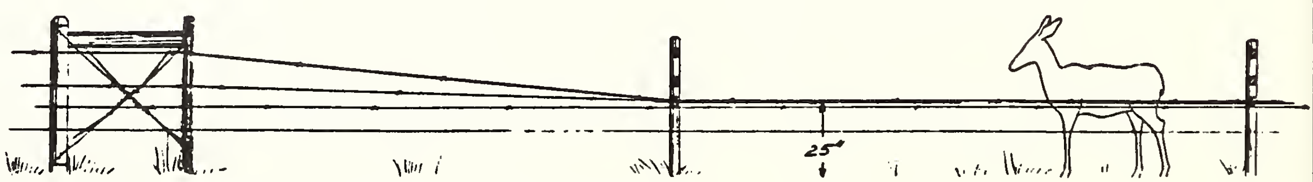


Figure 2b. Modification allowing nearly free movement.

Four-strand, 42-inch deer fence modification

Figure 4-53. Fence modification for big-game passage.

Source: Anderson and Denton 1980

Developments), many of which are applicable to wildlife. Yoakum et al. (1980) described and illustrated techniques for developing water holes, springs and seeps, reservoirs and small ponds, water catchments (guzzlers and dugouts), and modified water developments and safety devices, with supporting references. The U.S. Bureau of Land Management (1967) Engineering and Construction Manual, the USDA Forest Service (1974b) Watershed Structural Measures Handbook, and Wilson and Hannans (1977) provided additional descriptions and illustrations.

In the West, water has been the main limiting factor in developing wildlife habitat. The U.S. Soil Conservation Service recommends that facilities be designed to supply the following water requirements shown in Table 4-23.

Except for antelope, water should be located near dense cover. Livestock and big game should be fenced out of facilities for small mammals and birds.

Springs and Seeps

Generally, a spring or seep needs a protective installation, such as a spring box, to catch and store water (Figure 4-54). Such an installation should be fenced to prevent trampling damage by animals. Water from the spring box should be piped to a trough that

Table 4-23. Recommended watering requirements for various species

Species	Water Requirement (gallon)	Facility Spacing (mile)
Mule deer	1-2/day	1-3
Antelope	1-2/day	2-3
Elk	5-8/day	1-3
Moose	5-8/day	-
Quail	750/covey/yr	1/2-1
Chukar	750/covey/yr	1/2-1
Turkey	500/flock/summer	1-2
Mourning doves	2-5/day	3-5
Pheasant	2-5/day	1/2-1
Songbirds	1-2/day	1/4-1/2

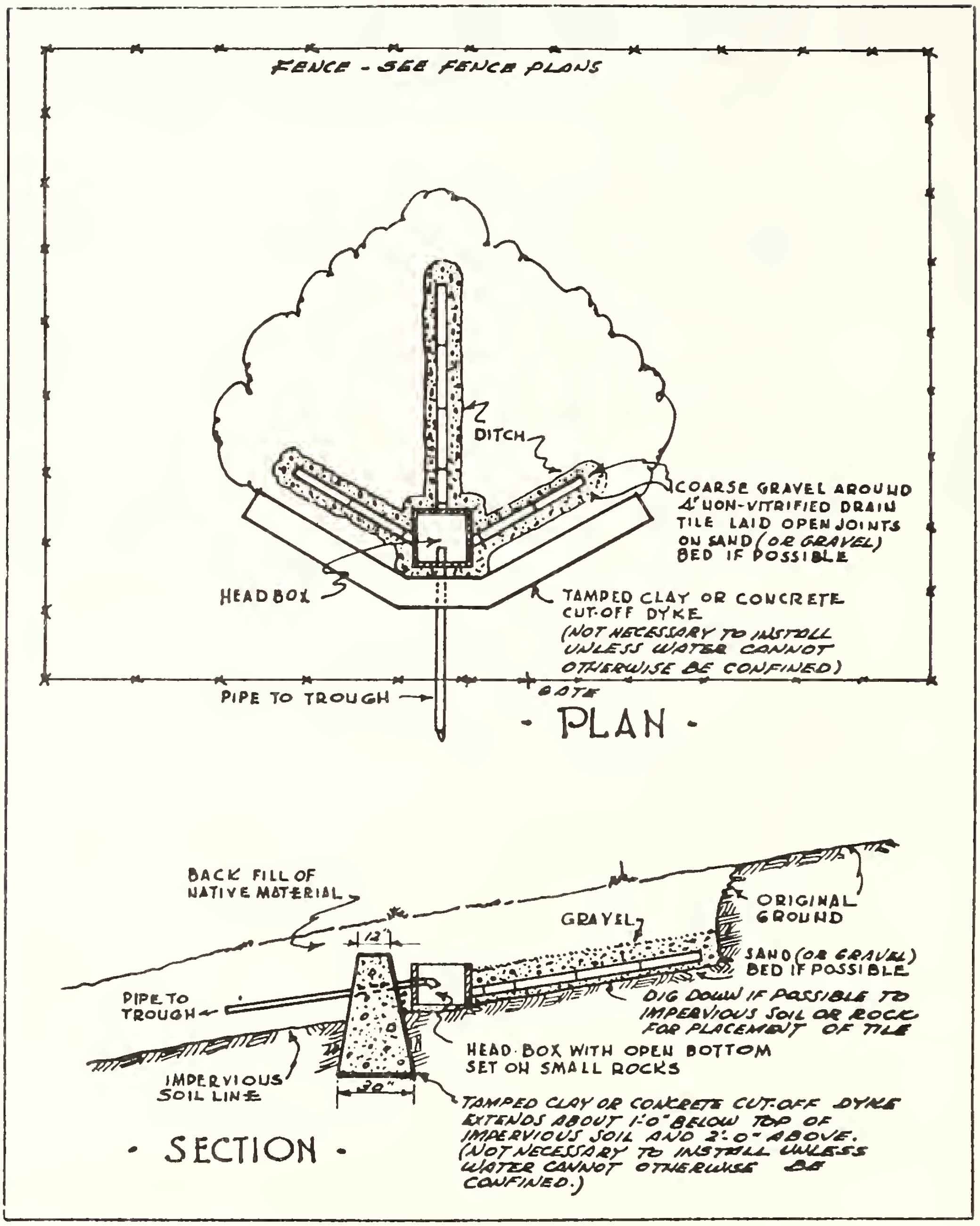


Figure 4-54. Spring development and collection of water.

Source: USDA Forest Service 1969b

will collect water, making it available in a drinking basin. Once water is collected and conserved, springs with very small volumes often can supply enough water to maintain wildlife. However, the development should be large enough to ensure that water will be available throughout the period when needed. The inside of the trough should be flat and contain provisions for wildlife to escape from the water if they fall in.

Spring developments originally planned for livestock use also can serve wildlife needs. In such instances, water should be provided for wildlife at the source and at appropriate intervals along pipelines used in the installation.

Construction Procedures

Before a spring or seep is developed, the reliability and quantity of its flow should be checked. Intermittent springs can be developed if adequate checks show that water is available for the intended period of use. It is sometimes advisable to provide a large capacity storage at intermittent springs and streams so that water will be available after the spring or stream stops flowing. Springs and seeps should be dug down to firm ground, hardpan, or rock to obtain maximum flow. The sources of a spring, whether one or several, should be directed to a collection basin. Water sources and collection basins should be fenced. Where ground is wet or soggy, tile can be used to collect the water.

Either galvanized iron or plastic pipe should be used. All standard pipe fittings are available for plastic pipe. Fit a short piece of galvanized pipe through the wall of the spring box to obtain a watertight bond.

The pipe should be large enough to carry the flow of the spring, but not less than 1-1/4 inches in diameter. The end of the pipe should be fitted inside the spring box with a "T," which will help prevent debris from entering the pipe.

The pipe should be laid on a minimum grade of 1 percent. If plastic pipe is used, it should be covered with soil to protect it from trampling and rodent damage. If galvanized iron pipe is used, it should be laid deep enough under the soil to protect it from freezing.

The pipe should be laid as straight as possible to the base of the trough where a "T" should be installed with a plug to allow cleaning and draining. When troughs without float valves are used, the vertical inlet pipe should be located from the "T" below ground on the outside to the top of the trough with an elbow and short nipple over the edge, and it should be fastened to the trough. This provides available water. If it is necessary to have the pipe above ground, support it with horizontal poles, which are supported by posts or small rock jacks.

Another method of construction is to collect and concentrate the flow of spring and seeps into a single stream that will not freeze readily and that will be available yearlong. Plastic sheeting and perforated pipe should be covered with coarse gravel (Figure 4-55). If necessary, vegetation should be restricted to increase volume. Livestock and big game should be fenced out at the source. A small pit should be blasted or dug a short distance below the source to concentrate the water and stimulate vegetative growth for wildlife by blasting or digging.

Escape Ramps and Ladders

Where water is not provided in a natural setting, birds and mammals will seek it from tanks or troughs. To provide a means of escape and thus reduce the hazard of drowning, floats, ramps, or ladders should be placed in the facility. The best design will incorporate such a facility into the trough structure. Any float, ramp, or ladder placed in a livestock water development should be relatively maintenance free and designed so that it neither interferes with nor can be damaged by livestock. Some suggested approaches are shown in Figures 4-56 and 4-57. Following are some general guidelines:

(1) Provide at least one escape route to and from the water. Take advantage of the natural terrain or vegetation where possible.

(2) Provide an alternate escape route where feasible.

(3) Fence spring developments from domestic livestock. Fences can serve a dual purpose: preservation of the water source and protection of environment needed for small forms of wildlife.

(4) Protective fences should be negotiable by wildlife, except where trampling or wallowing by big game will damage the spring source.

(5) Fenceposts should be pointed to discourage perching by avian predators.

(6) Provide a natural drinking environment.

(7) Provide safety from wildlife drowning in drinking troughs and tanks by installation of ramps.

(8) Maintain or provide adequate cover surrounding the watering area. This can be accomplished naturally or artificially by means of plantings, brush piles, buried drain tiles, fencing, and the like.

(9) Where applicable, provide an information sign to inform the public of the development's purpose.

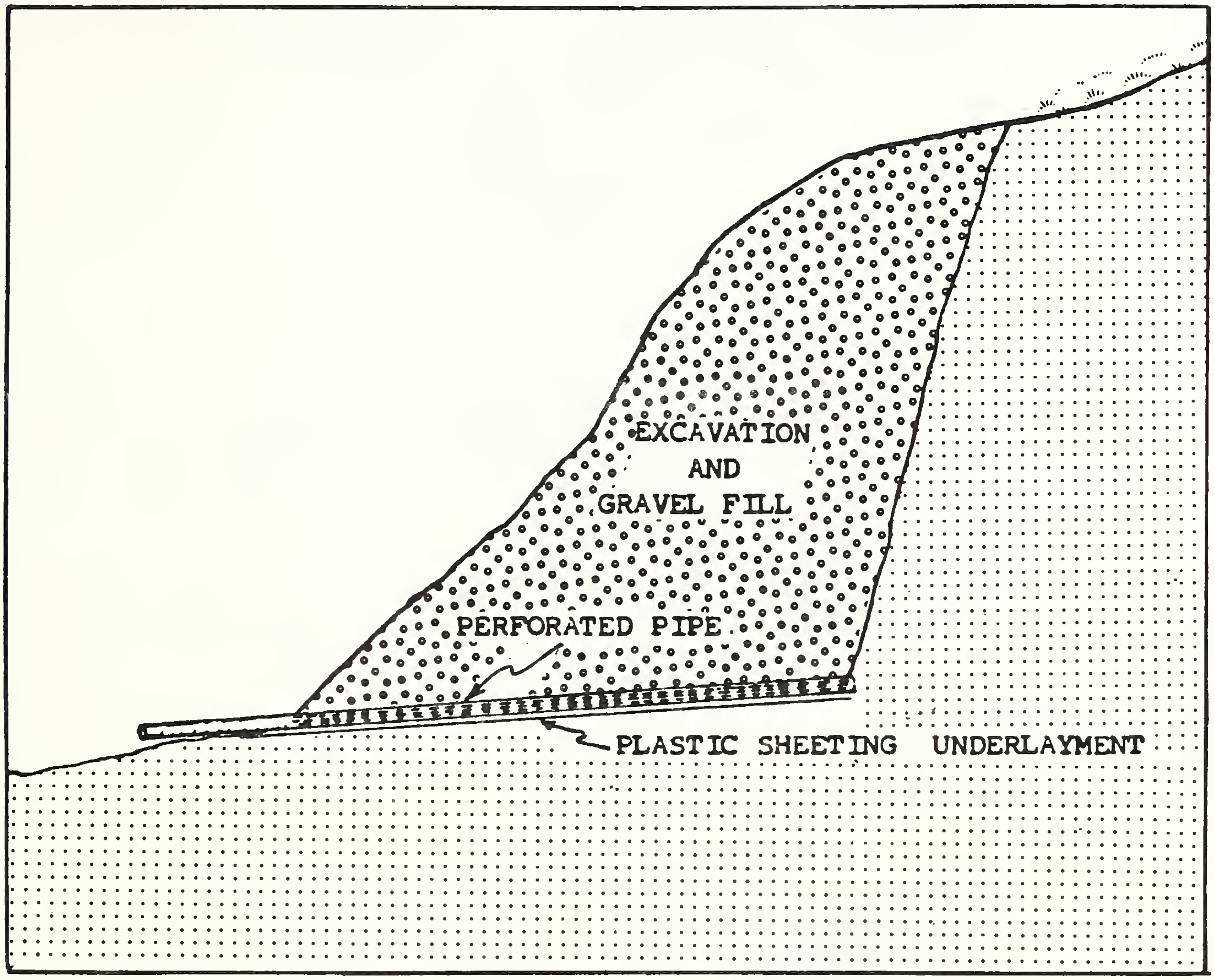


Figure 4-55. Constructing springs and seeps.

Source: Rutherford and Snyder 1983 (Diagram by W. D. Snyder)

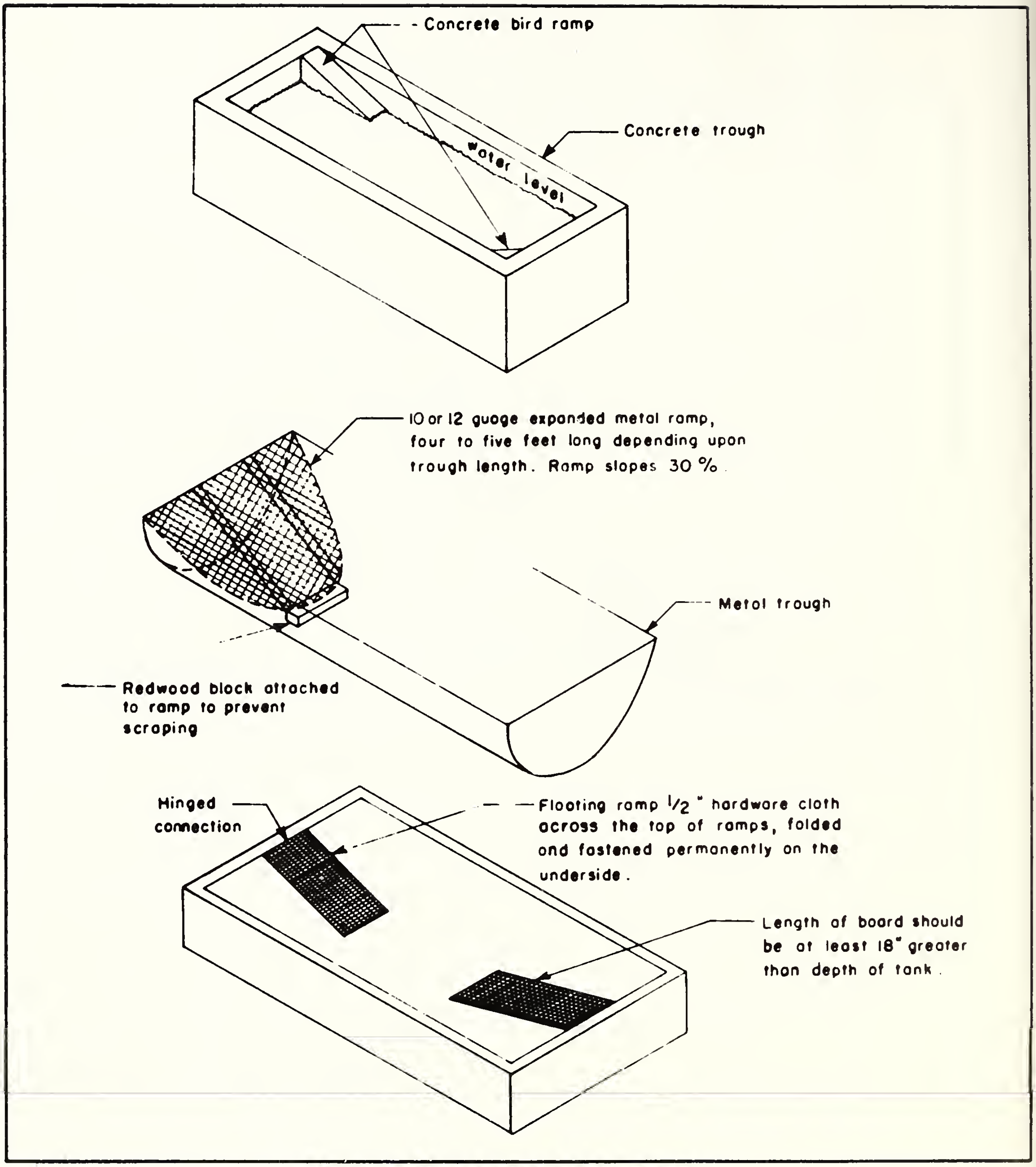


Figure 4-56. Trough bird ladder.

Source: USDA Forest Service 1969b

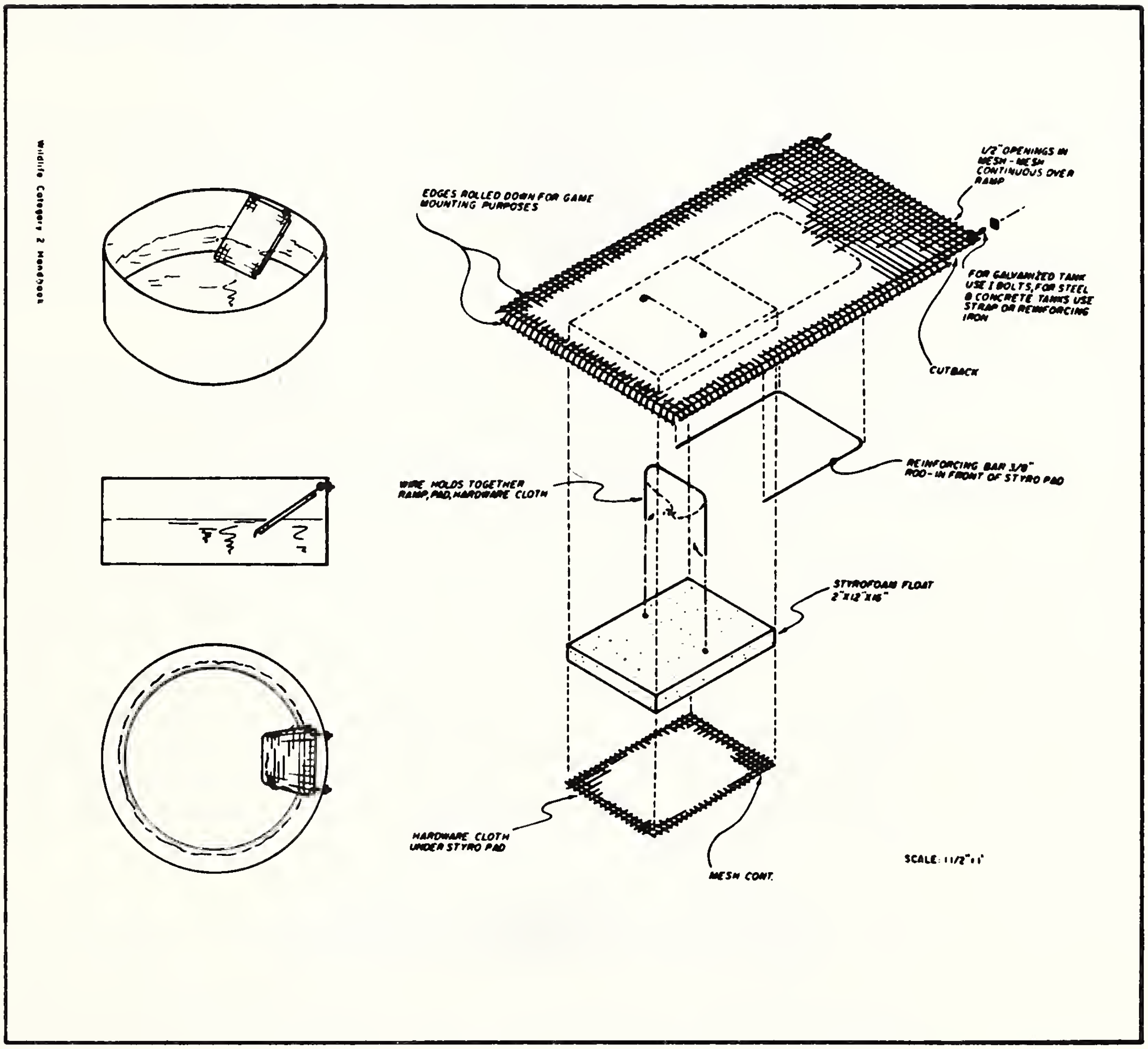


Figure 4-57. Small game escape ramp.

Source: USDA Forest Service 1969b

(10) Where appropriate, at fenced developments, provide public access to the water by piping it outside of the exclosure for human use.

(11) Extend part of trough or provide a trough outside of fence when livestock use is planned.

(12) Pipe water for human consumption some distance from wildlife water, if shy animals are involved. For example, it is recommended that sustained camping be discouraged within 1/2-mile radius of desert bighorn sheep waters in areas where this element is scarce.

Horizontal Wells

To enhance success, horizontal wells should be developed in accordance with the presence of historical springs and seeps, the distribution of phreatophytes (Meinzer 1927), and the presence of appropriate geological formations (Welchert and Freeman 1973). Dike and contact formation springs (Figure 4-58) are suitable. Drilling equipment to tap the aquifer must be relatively light and portable (about 1,500 to 2,000 pounds) to be towed or helicopter-lifted into rugged terrain.

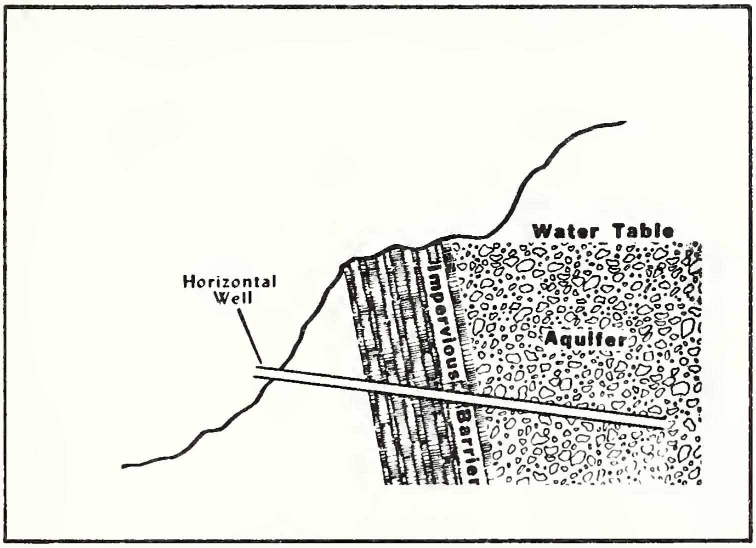
Two hydraulic systems operate the drilling machine, one providing power for the drill chuck rotation and the other operating the movement of the chuck assembly along the carriage to move the rotating drill stock into or out of the hole being drilled. The drill stock is an extra-strong link of 21 feet by 1.25 inches of steel pipe rotated in a chuck at about 100 revolutions per minute. Drilling speed is a function of the type of bit used, the rotational speed of the drill stock, the type of material being drilled, and the thrust applied to drill stock by the operator.

Drilling continues until water is produced or the well is determined to be dry. If water is reached, the well is finished by installing a standard 2-inch pipe and cement, with proper plumbing connections (Bleich et al. 1982). A pipeline as long as 10 miles can be run to a concrete drinking basin or commercial steel cattle trough with float valve.

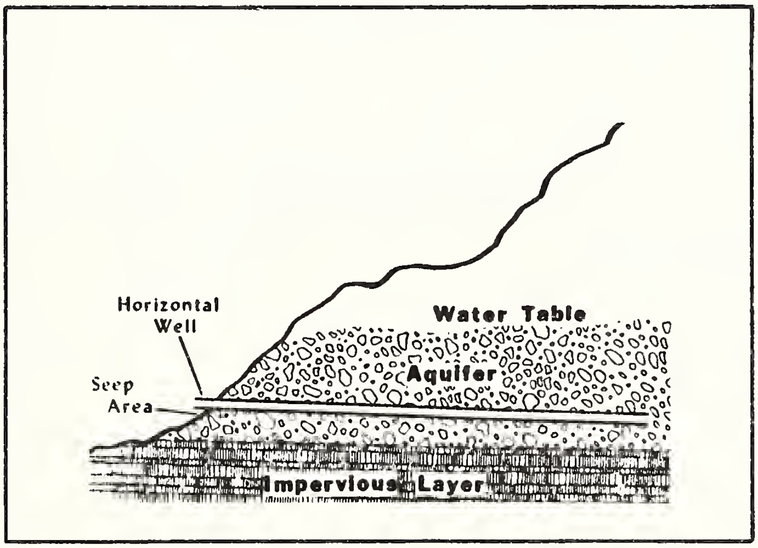
Waterholes

Waterholes are open water storage structures, both natural and artificial, that are available for wildlife use. Water is such a basic requirement that waterholes, especially in dryland areas, are the hub of wildlife activities. All waterholes, whether built primarily for livestock or wildlife, should be designed for use by all kinds of animals. Waterholes should be designed to reduce competitive use at and next to the waterhole.

Any surplus water from fire, recreation, or other storage tanks should be made available to wildlife. Several simple plans for this class of development are satisfactory. Figure 4-59 shows two that use an overflow from a water tank. These improvements are inexpensive and require little maintenance, but they are of high



Dike formation spring showing relative positions of the impervious barrier, aquifer, and horizontal well casing. From Welchert and Freeman (1973).



Contact formation spring showing relative position of the impervious layer, aquifer, and horizontal well casing. From Welchert and Freeman (1973).

Figure 4-58. Horizontal wells.

Source: Bleich et al. 1982

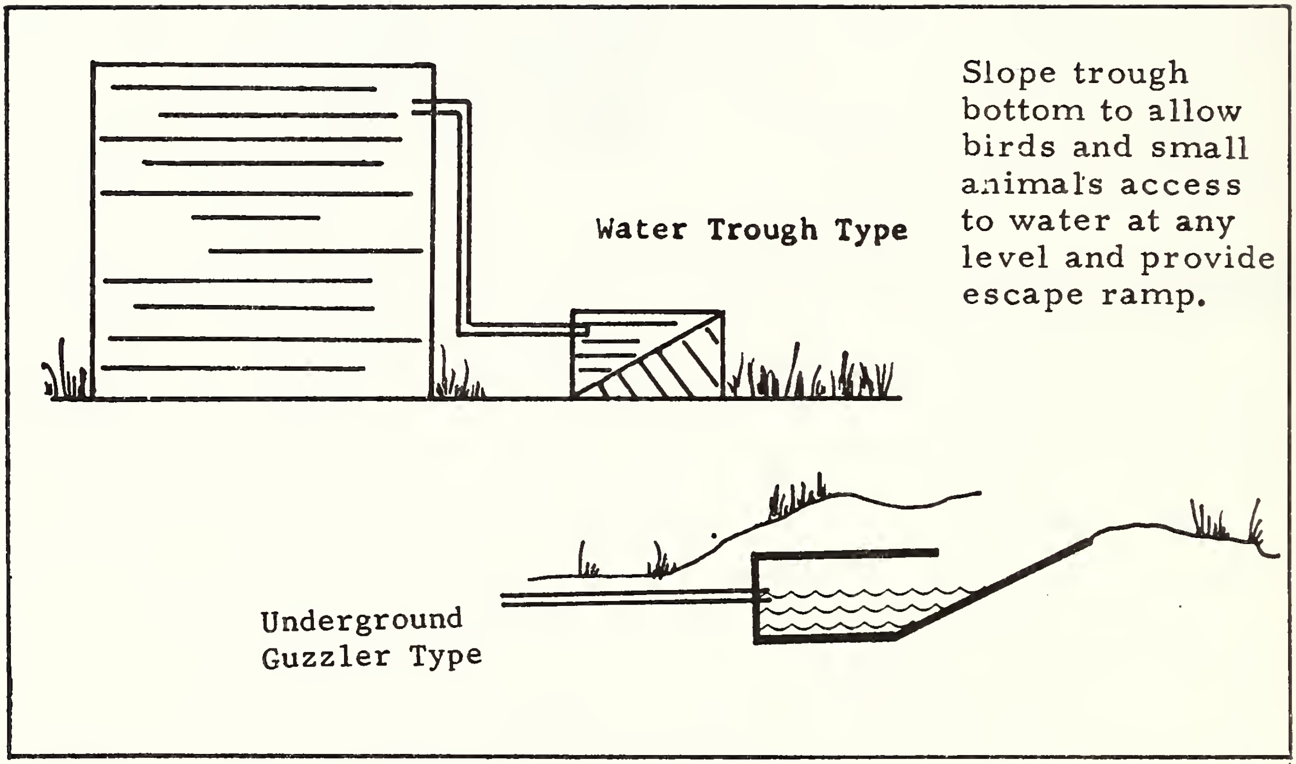


Figure 4-59. Waterholes using tank overflow.

Source: USDA Forest Service 1969b

value in areas with short water supplies. They should not be installed where the water supply is of an intermittent or undependable nature, as several days' shortage during hot weather may result in loss of upland game birds or other species that have become dependent upon the water source.

Dugouts

Dugouts or pit tanks about 20 feet by 20 feet are usually built with vertical sides and a 4:1 slope on the ends when soil conditions permit. This gives a steep-sided waterhole with little surface area, no shallow area, and no food for waterfowl. Floating resting platforms, anchored in the middle of the dugout, are effective in encouraging greater use of these small bodies of water by birds. Fenced areas next to this type of waterhole also add to its attractiveness for wildlife.

Guzzlers

The guzzler is a permanent, self-filling water catchment similar to a cistern. Its greatest value is in semiarid regions where natural waters are scarce or widely spread. When water is a limiting factor, the range capacity for certain wildlife species is increased through installation of guzzlers or other water devices. Guzzlers are most commonly installed for the use of upland game birds. A larger but similar version often is used for deer, bighorn sheep, or other big game.

Essentially, the guzzler installation consists of a watertight tank set in the ground, which is filled by an apron. This apron collects rainwater and drains it into a tank where it is stored for use by wildlife in the summer. The structure is simple and requires a minimum of maintenance. The ordinary guzzler permits birds and other small animals to enter the covered tank through an open end and walk down a sloping ramp to the water level. When use is directly from the storage tank, there is no need for float valves or other regulating devices.

<u>Site Location</u>

The most important step in installing a guzzler is locating an adequate site. A guzzler should never be placed in a wash or gully where it will collect silt or sand or be damaged by floodwaters. The size of the water-collecting apron should be proportioned so that the cistern will maintain an adequate water supply from rainfall. Since the cost of digging the hole for the cistern is one of the largest items of cost, a site should be chosen where digging is comparatively easy. The tank should be placed with its open end away from the prevailing wind and, if possible, facing in a northerly direction so that a minimum of sunlight will enter the tank. This will reduce algae growth, water temperature, and evaporation.

In addition to purely physical characteristics, take care to choose a site acceptable to the target species. For quail, choose a general location where roosting, loafing, feeding, and escape cover

are present in proper relationship, and where abundant food supplies are available. In checking a quail range, remember that a small amount of water is enough for a covey of birds so long as it is permanent. Each quail will use about 1/2 ounce per day and, depending on the length of the dry season, 3 quarts per year.

A guzzler is more effective for quail if a clump of brush or other escape cover is immediately adjacent. A good roost tree is desirable within 100 to 200 yards of a watering site. However, it is best not to locate guzzlers beneath or so close to trees that leaves and branches will litter the collecting apron.

Construction Material

The cisterns used for guzzlers usually are made of either concrete or plastic. Steel tanks sometimes are used. The plastic guzzler is a prefabricated tank constructed of fiberglass impregnated with a plastic resin. If the construction site is a long distance from a source of washed aggregate, or if labor costs are high, plastic guzzlers offer savings in transportation and labor costs.

For concrete guzzlers, only washed gravel aggregates should be used for construction; otherwise, the concrete may start to disintegrate after 5 or 10 years. Steel tanks are used for guzzlers on some National Forests and are reported as being satisfactory. Asphalt coating is used to minimize rusting.

Collecting aprons are made of many materials. Concrete sealed with bitumul, galvanized metal sheet roofing, glass mat and bitumul, rubber or plastic sheets, asphalt, and plywood have all been used successfully. From the standpoint of maintenance costs, durable materials such as concrete or metal have proved most satisfactory.

Size of Watershed

The size of the water-collecting apron or surface needed to fill a guzzler will depend on the size of the guzzler and the minimum annual rainfall expected at the construction site (Table 4-24). Actually, the size of the needed interception area will prove surprisingly small because nearly 100 percent of the rainfall is retained. Calculation of the potential yield of the rainfall collection surface can be determined by the following formula:

$$\frac{\text{Surface area (ft}^2\text{) of apron}}{12} \times 7.4 = \text{gallons per inch of rainfall}$$

It is important to calculate on the basis of the minimum of precipitation expected, rather than the average or maximum, to prevent guzzler failing during drought years.

Table 4-24. Size of apron needed for 600-, 700-, and 900-gallon guzzlers.

Minimum Annual Rainfall (inches)	Collecting Surface Required (square feet) 600	700 (gallons)	900	Apron Dimension in Feet: Square 600	700 (gallons)	900	Circular 600	700 (gallons)	900
1	965	1,127	1,453	31	34	38	36	38	43
2	482	563	726	22	24	27	25	27	31
3	322	376	485	18	19	22	20	22	25
4	242	282	365	16	17	19	18	19	22
5	192	225	290	14	15	17	16	17	19
6	162	189	243	13	14	15	15	16	18
7	138	161	208	12	13	14	13	14	16
8	121	141	182	11	12	14	12	13	15
9	107	125	161	11	12	13	12	13	14
10	97	113	146	10	11	12	11	12	14
11	87	102	132	9	10	11	10	11	13
12	80	94	121	9	10	11	10	11	12

Note: Aprons ordinarily are constructed on the ground surface, but where galvanized metal sheet roofing is used, it is placed on a frame with an air space between it and the ground to prevent rusting.

Constructing Concrete Guzzlers

Plastic guzzlers are generally cheaper than concrete. Following are installation instructions for those areas where concrete is still used:

(1) Select the site and clear the apron. Lay out the excavation site for the guzzler. To square the outline, measure diagonally from each rear corner to opposite front corner and adjust stakes until these are equal. Excavate the rear portion to required depth; slope ramp at front to ground level. Line excavation with laminated Kraft paper.

(2) Assemble reusable "Ply form" forms for inner walls and hang in position with 4-inch clearance between forms and walls and floor. Level the forms and pour concrete between forms and walls of excavation. Tamp and vibrate walls. Pour enough concrete to complete floor and ramp. Trowel smooth, allowing 1/2-inch clearance between edge of form and ramp.

(3) Remove wall form carriers, assemble reusable roof forms, place in position, and cover with three thicknesses of Kraft paper. Place dishpan in position for manhole. Cover roof with 3 inches of concrete. Place 3 inches of concrete inside the dishpan. Insert a loop of heavy wire or 1/4-inch reinforcing rod at center of manhole cover to serve as a handle. Provide a 6-inch curb at front end of guzzler roof. Pour 3-inch skirt 3 feet wide in front of guzzler ramp and provide a 6-inch trash wall.

(4) Outline apron. Excavate a settling basin 18 inches in diameter and 8 inches deep in front of skirt. Cover the entire apron and basin with Kraft paper and pour concrete 3 inches thick. Trowel smooth and provide a 6-inch trash wall around the circumference of the apron. Make a hole 3 inches in diameter through trash wall for screened inlet to guzzler. Mark holes for 1/2-inch iron coyote guard at 4-inch intervals across front of guzzler. Cover all fresh concrete with paper to ensure proper curing.

(5) Allow concrete to set for 24 hours. Remover paper and forms and wash inside of guzzler with cement and water. Apply asphalt emulsion to apron. Install coyote guards. Cover roof with 10 inches of soil to stabilize temperature within cistern. If domestic livestock graze the area, the entire guzzler should be fenced against stock so there will be no chance of damage to apron, tank, or lid. When the guzzler is constructed after the rainy season, it is best to fill it with water to aid in curing concrete and to ensure bird and animal acceptance.

Constructing Other Types of Guzzlers

Other types of guzzlers include the quail guzzler, which incorporates the same general principles as the concrete guzzler but is dissimilar in many respects (Figures 4-60 and 4-61). This illustrates the flexibility and diversity of design that has been characteristic of guzzler development in various regions. The iron roof should have a gentle slope of about 5 percent for best performance, and it should be relatively smooth to prevent water from standing on the surface. Runoff is caught at the bottom of the aprons and carried in pipes to the storage container. Following are materials needed to construct a guzzler designed similarly to that in Figure 4-60.

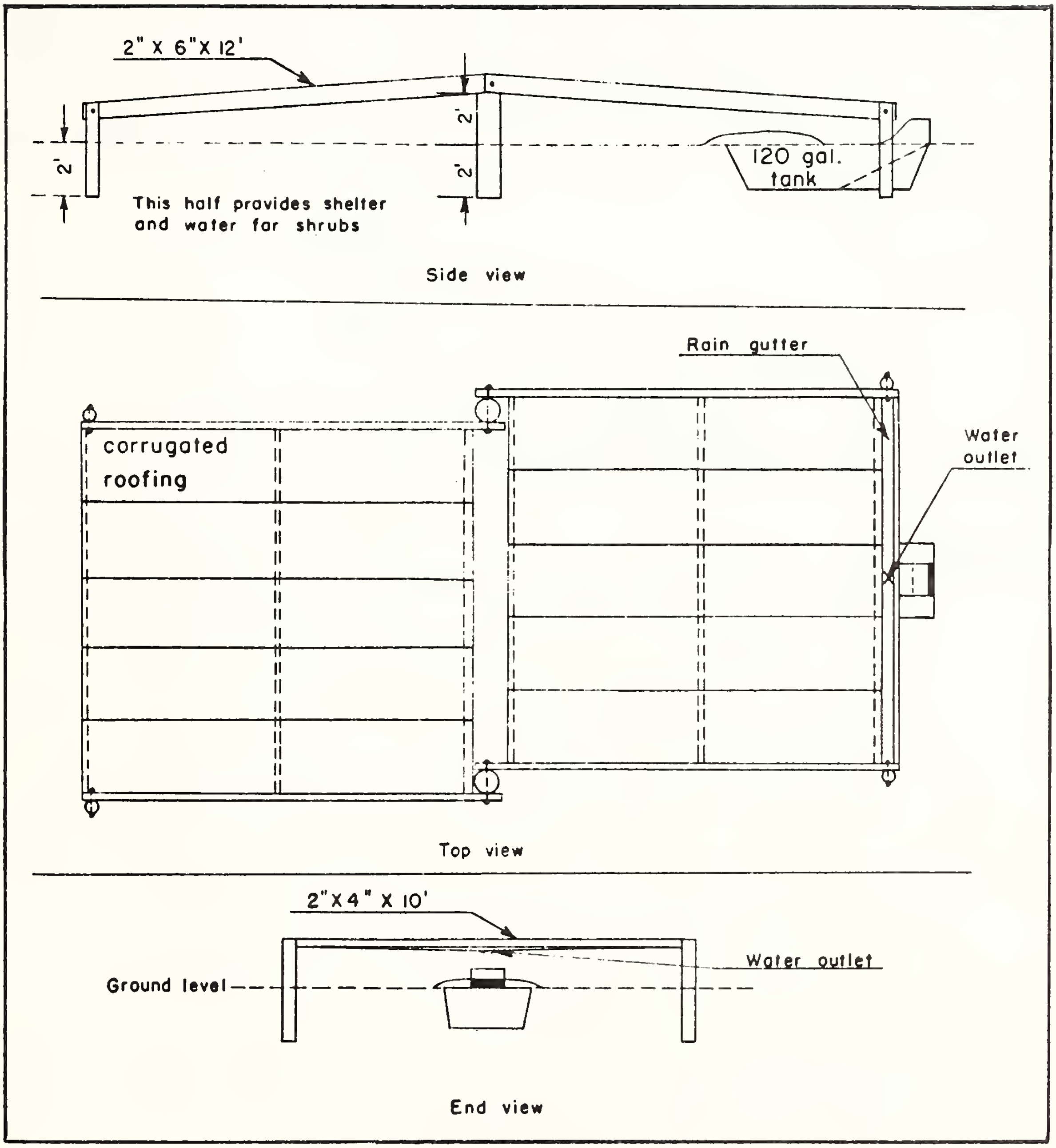


Figure 4-60. Quail guzzler.

Source: USDA Forest Service 1969b

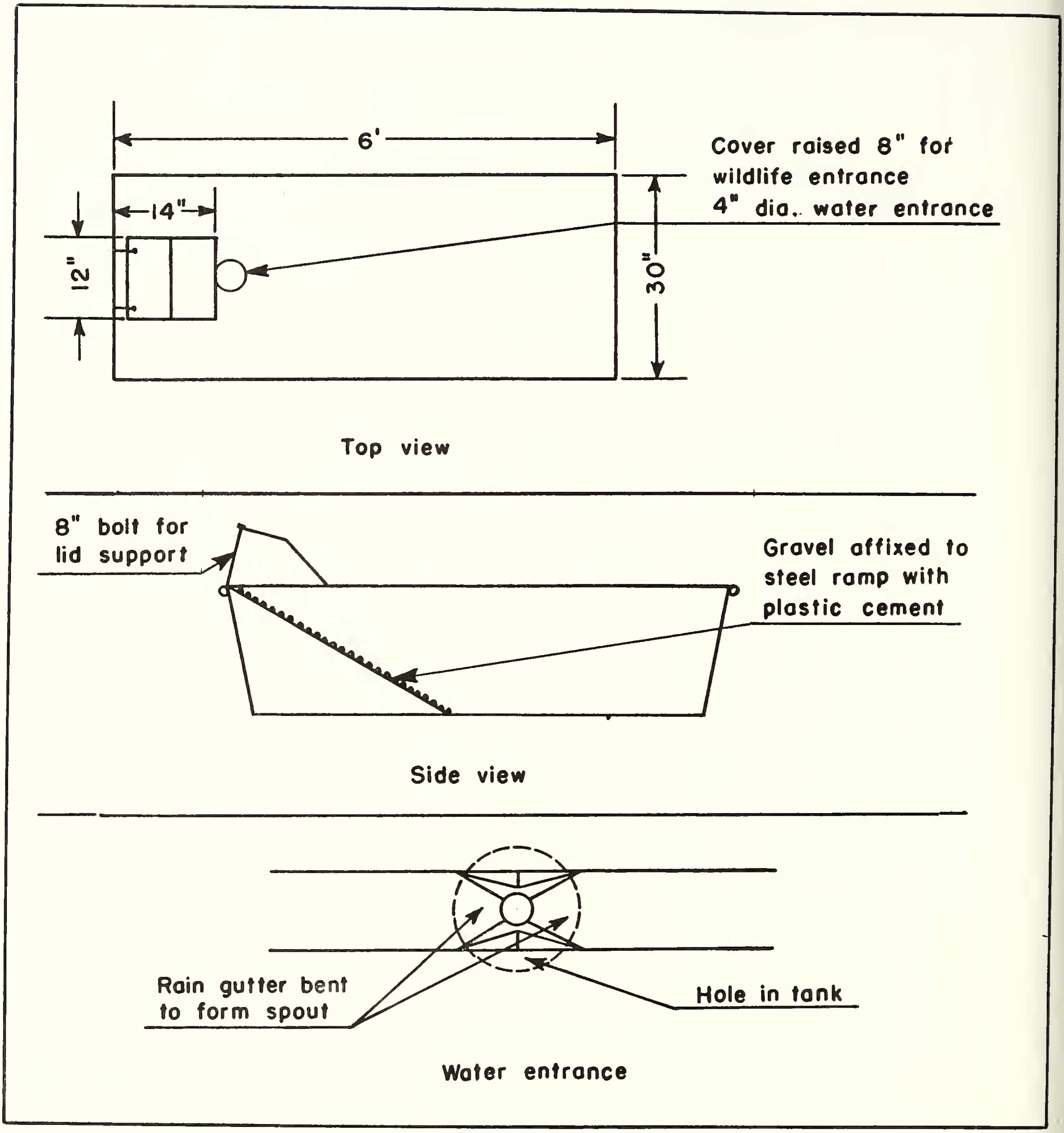


Figure 4-61. Guzzler tank.

Source: USDA Forest Service 1969b

4 - 2" x 6" x 12' pressure-treated pine or Douglas fir
7 - 2" x 4" x 10' pressure-treated pine or Douglas fir
10 - 24" x 11' 28-gauge galvanized corrugated steel
2 - 5' galvanized rain gutters
1 - 8' x 4" creosote-treated post cut in half
2 - 6-1/2 ' x 3-1/2" creosote-treated posts cut in half
1 - 120-gal. rectangular tank 6' x 2-1/2' x 16"
1 - 1' x 3' 14-gauge steel ramp
1 - 2-1/2 ' x 6' 14-gauge steel tank top
2 - 9" x 3/8" bolt
4 - 6" x 3/8" bolt
2 - 8" x 3/8" bolt
24 - 3/8" washer
#2 - Lead-headed nails
Plastic cement for affixing gravel to ramp

In some localities the storage tank is closed at all ends, or a storage bag is used, and the water piped by gravity flow to a small trough. Here the flow is regulated by a float valve. Where such valves are in use, maintenance checks should be regularly scheduled to ensure that the valve is functioning during the season when water is needed. Figure 4-62 shows the general layout for such an arrangement.

The most foolproof deer guzzlers are those in which an arrangement allows the animal to drink directly from the storage tank. More commonly for deer and other large animals, a trough with a float valve is used.

Tanks and Troughs

All tanks and troughs need a floating platform, fastened to one edge, that extends across the tank, ramps, or ladders allowing avenues of escape. Yoakum et al. (1980) list guidelines from Wilson and Hannans (1977) for adapting livestock water developments to wildlife.

Providing water during winter can be accomplished with 8-foot rubber tires holding 350 gallons. The black rubber absorbs enough heat by day to keep the water from freezing at night according to the Intermountain Region of the USDA Forest Service. Bird ladders should be installed.

Reservoirs and Small Ponds

The term "reservoir" as used here refers to water impounded behind a dam. It may be formed by building a dam directly across a drainage or by enclosing a depression to one side of a drainage and building a diversion ditch into the basin. This type of water supply is most important in the foothill zone of National Forests and on the plains where water is often in short supply. All wildlife species will use lakes and reservoirs. When planning such developments, fully consider the various kinds of uses that may be made of the water.

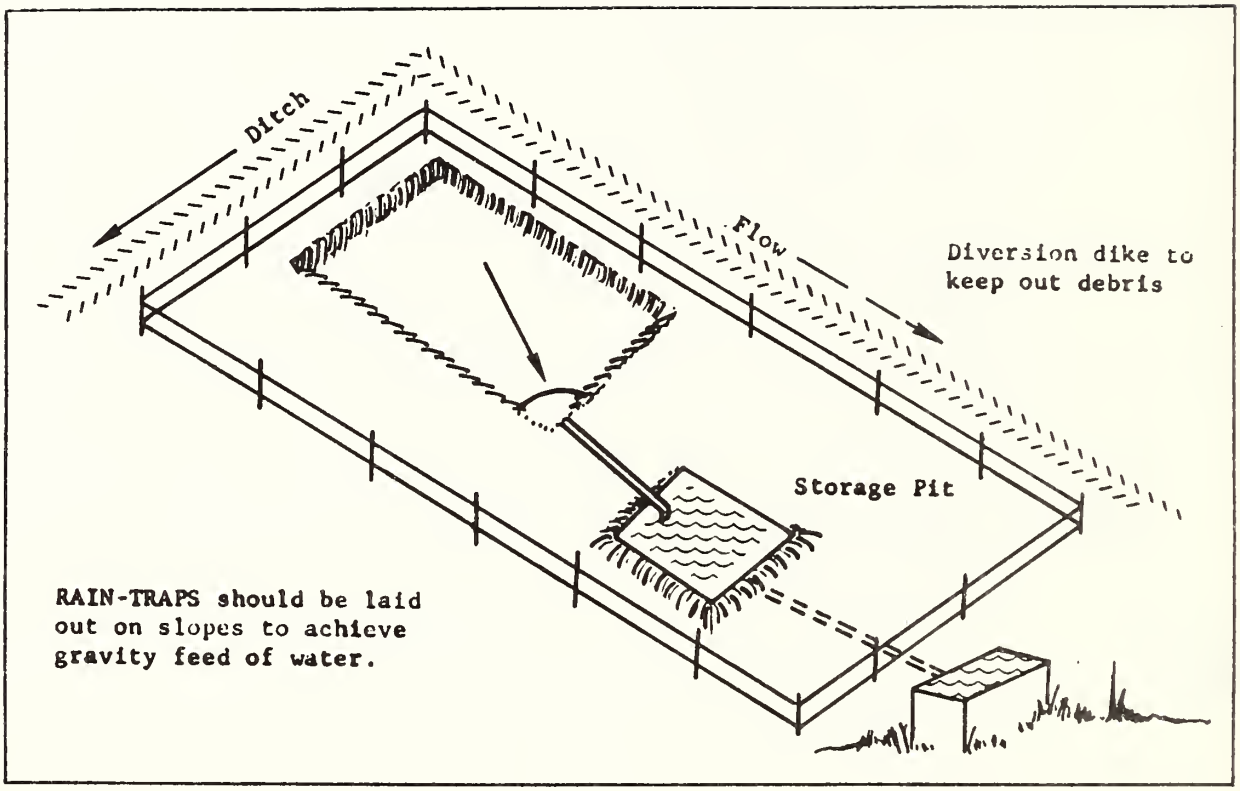


Figure 4-62. Water development, storage pit, and trough diagram.

Source: USDA Forest Service 1969b

Basic design of reservoirs should seek maximum storage with a minimum of surface area to avoid evaporation loss. Steep sides in the waterhole are desirable to prevent bogging and roiling the water as livestock and big game come to drink. Although steep sides are excellent for hoofed animals, they are a poor design for waterfowl and upland game. The best procedure is a combination of features, which can be maintained only by fencing hoofed animals out of the bird areas.

Physical characteristics of impoundments, which are attractive to dabbling ducks, are grassy, gently sloping shorelines with shallow areas and mud flats. Islands are attractive to waterfowl. A pond should be constructed near cover, be 40 to 80 feet across and at least 4 feet deep at the deep end, preferably in an area where it will fill with groundwater. At least 1/3 of the bank should have a 4:1 slope. Spoil material should be spread from construction uniformly no higher than 3 feet, and the area should be seeded immediately with a mixture of grasses and legumes to reduce erosion and provide food and cover. Desirable emergent vegetation should be introduced when it is not present. Tree cover, especially around small reservoirs, is not preferred by waterfowl. Shrubs, such as chokecherry, Russian olive, wild plum, and snowberry, do not inhibit duck use, and they provide a desirable habitat for small game and upland game birds (Figure 4-63). If necessary, the area should be fenced from livestock. In some States, impoundments 1/10 acre or larger must conform with State regulations governing mosquito control and other measures on impounded waters.

Rock piles of riprap placed along the north shore of ponds 1 acre or more will be used as sunning sites by snakes and turtles and as shelter by bullfrogs and salamanders. To encourage amphibians, no fish should be stocked (Johnson 1983). Brush piles and tree branches should be placed in shallow water 2 feet or less for egg laying. At least one-quarter of the total pond bank should have some downed tree branches. In most ponds, 5 to 10 logs, 5 to 8 feet long and 6 inches in diameter, should be placed with part of the log in the water, preferably with the entire underside of each log in contact with the bottom.

Selecting Reservoir Sites

The following points should be kept in mind when selecting a site for a reservoir:

(1) When reservoirs are for livestock and wildlife use only, they should be no larger than is needed to serve the forage area in which they are located.

(2) The most suitable soils for dams are clays with a fair proportion of sand and gravel (one part of clay to two or three parts grit). Straight clay soils crack badly upon drying and are apt to slip when wet. Seek advice from a soil scientist.

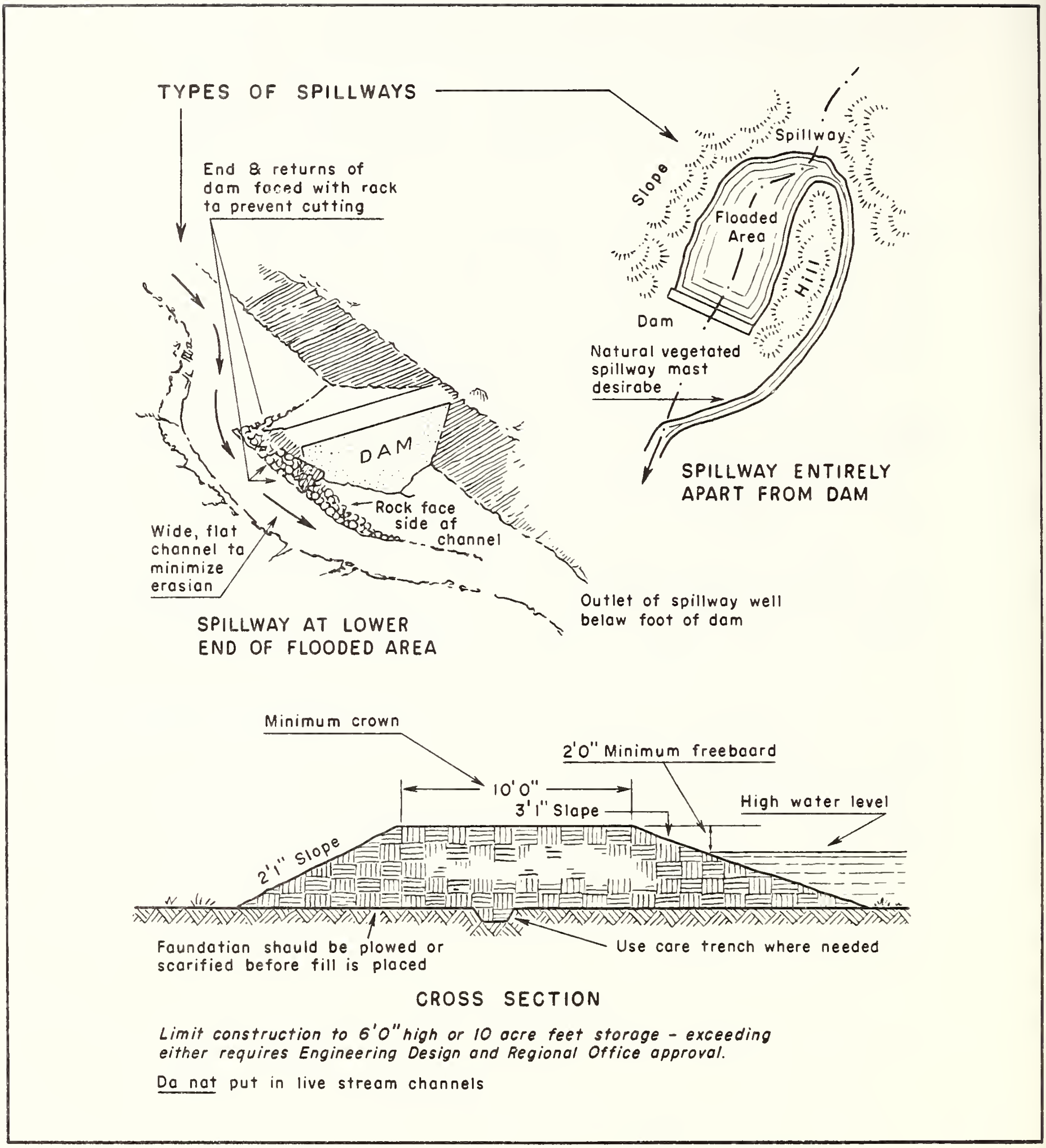


Figure 4-63. Earth-filled dam reservoir development.

Source: USDA Forest Service 1969b

(3) The watershed above the dam should be large enough to provide enough water to fill the dam without excessive danger of flood damage.

(4) The most economical site is one along a natural drainage where the channel is narrow, relatively deep, and the bottom is easily made watertight. The channel grade immediately above the dam should be as flat as possible.

(5) Wildlife should have easy access to the water.

(6) If possible, locate the dam to take advantage of natural spillway sites.

Constructing Dams

(1) The Forest engineer should survey and stake out the dam site before construction begins. If there is any question as to suitability of material for dam construction, a soil scientist should examine it.

(2) The dam site should be cleared of trees, brush, roots, rocks, and debris, unless some cover is needed for fish. Also, trees and brush should be removed from the reservoir site, unless some cover is needed for fish.

(3) Plow or scarify the foundation area of the dam in the direction of the main axis of the dam, so that there will be a good bond between the foundation and the fill material. On sites where stability and permeability of the foundation materials are questionable, a narrow core trench should be dug lengthwise to the dam, then refilled and packed with damp clay soil (see Figure 4-63).

(4) Where suitable material is available above the dam, it should be obtained so that the borrow pit will become part of the reservoir and add depth to the impoundment.

(5) The base thickness of the dam must be equal to or greater than four and one-half times the height plus the crest thickness. The slopes of the dam should be 2-1/2:1 on the upstream face and 2:1 on the downstream face.

(6) Minimum width of the top of all dams should be 10 feet.

(7) The fill of the dam should be at least 10 percent higher than the required height to allow for settling.

(8) Freeboard (depth from the top of the dam to the high watermark, when the spillway is carrying the estimated peak runoff) should not be less than 2 feet.

(9) To minimize evaporation loss, reservoirs should be built for the greatest possible ratio of depth to area.

Constructing Spillways

The spillway should have a capacity double that required to handle the largest known volume of runoff and be designed to prevent the water level from ever rising higher than within 2 feet of the top of the dam. If available, a natural spillway is preferred. It should have a broad, relatively flat cross section; enter well above the fill; and reenter the main channel some distance downstream from the fill.

A spillway should be wide, flat-bottomed, and protected from washing by riprapping (facing with rocks). The entrance should be wide and smooth, constructed with nonerodible materials, and the grade of the spillway channel mild so the water will flow through without cutting. It should reenter the main channel well below the dam in such a manner as to prevent erosion (see Figure 4-65).

Seepage

New reservoirs usually do not hold water satisfactorily for several months. "Puddling" the soil by livestock trampling can be encouraged by salting in the bottom of the reservoir before it fills. It may be necessary to spread bentonite over the bottom and sides of the pit and face of the dam. Samples of the reservoir bottom, dam material, and the bentonite should be tested to determine how much bentonite to apply. Bentonite is applied in several ways. The Forest engineer should be consulted to determine the most suitable procedure for the site.

Sand- or Rubble-Filled Reservoirs

Reservoirs that are built in drainages where the chances are high that the trough will be filled with sand or gravel may be made into permanent water sources by installing a pipeline through the dam during construction. The pipe should lead from a point about 5 feet upstream from the bottom of the dam and 1 foot above the bottom of the reservoir to a trough or troughs placed out of the main drainage at any desired point below the reservoir. The pipeline should be installed to permit gravity flow of the water, and the trough should be equipped with a float valve. The upper end of the pipe should be covered with a wire-screen basket, with the basket surrounded first by rubble, then by gravel, followed by coarse and then fine sand. Another satisfactory method is to perforate the upper 5 feet of the pipe and surround this portion with rubble, gravel, and sand in a like manner. Surrounding the upper end of the pipe this way is imperative to prevent the pipe from becoming clogged with silt. If available, a sand point should be used instead of the screen basket or perforated pipe. In order to prevent seepage where the pipe passes through the dam, the pipe

should be encased in two concrete collars 2 feet in diameter and 3 feet long, placed 3 feet apart. The silt, sand, or gravel that fills the reservoir becomes water-holding material, which releases water as needed to the pipeline. An added advantage is that evaporation is greatly reduced.

Other Planned Features

Other desirable features should be incorporated into the reservoir at the time of construction; these include fences, food, and cover plantings.

Fences. Fenced areas are the most efficient method of preserving an undisturbed area for wildlife. Exclusion of livestock grazing around waterholes will provide habitat for nesting and resting birds. The most desirable practice is to place a pipe through the dam fill during construction, leading to a series of water troughs below and away from the reservoir. If limited water supplies are involved, waterflow to the troughs should be controlled with float valves during the summer months. The whole dam and reservoir may be fenced for wildlife, or a portion of the reservoir may be fenced for wildlife and the balance left open to livestock. Use fencing specifications that permit the passage of game animals while excluding livestock.

Food and Cover Plantings. Planting vegetation around fenced ponds may be necessary. If desirable plant species are above the pond, or if there are older reservoirs upstream where the plants already grow, the area will vegetate naturally. If aquatic plants, such as reeds, sedges, and rushes, are desired, the area should be planted above the waterline in the spring. If seeds of aquatic plants are used, they should be soaked thoroughly and broadcast over the water surface and shore in the fall. Following are recommended plants to introduce in the reservoir of a fenced area: for herbaceous marsh plants, cattails, arrowheads, bullrush, smartweed, and pondweed; for upland shrubs, wild plum, snowberry, chokecherry, and serviceberry.

Sand Dams

Sand dams are inexpensive and control evaporation of collected waters. Loose sand and gravel should be cleared from the rock bottom of ephemeral streams in small- to medium-sized rocky canyons. A 1-inch galvanized outlet pipe should be built into the lowest point of a masonry dam at least 3 feet high anchored in the rock base (Figure 4-65). Numerous lengths of 12-inch diameter aluminum pipe, with or without 0.5-inch holes drilled in the top third about 1 inch apart, can be used to construct the holding basin and may or may not be connected to the outlet pipe (Bleich and Weaver 1983). A few large rocks or heavy wire screens over the end of the pipes will allow adequate filling and drainage. With the higher dam, the pipes may be layered to increase storage capacity, bolted together, and the bottom layer attached to the rock substrate with rebar or other suitable material by drilling into the rock to anchor the

system against heavy floods. The pipes must be covered with about 1 foot of coarse gravel and small rock. The water-collecting basin above the pipes must be filled about 3 feet deep with sand (Figure 4-64). Plastic pipe connects the outlet pipe to a small trough with a float valve. To prevent jamming of the float valve by foreign objects, which would drain the trough, a capped 6-inch diameter well-screen (Johnson screen) 1 foot long should be capped with a bell reducer to a 2-inch outlet pipe on the upstream side of the dam. A pipe 12 inches in diameter will hold about 5.9 gallons per foot of pipe (Table 4-25). Gray (1974) provided additional guidelines.

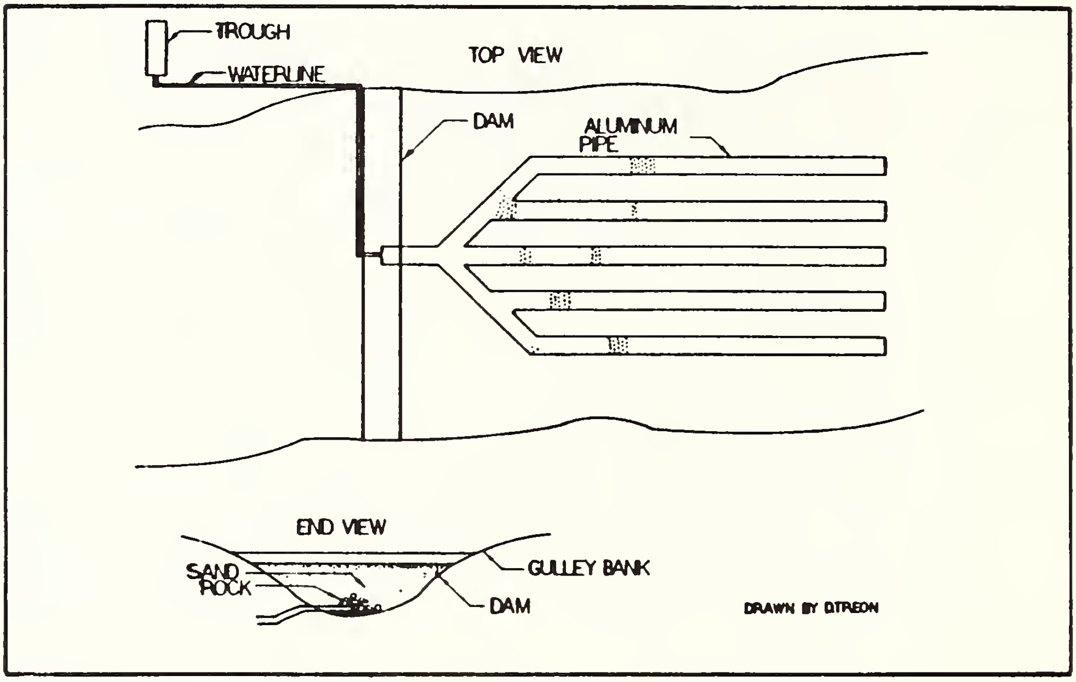


Figure 4-64. A schematic design of a sand dam for harvesting overland flow.

Source: Sivils and Brock 1981

Table 4-25. Storage of water in various-sized pipes that may be used in a sand dam water development.

Pipe Size (inches)	Gallons/Linear Foot
16	2.9
12	5.9
18	8.8
24	11.7

Source: Sivils and Brock 1981

MANAGING FOREST LANDS FOR WILDLIFE AND FISH

Several Forest Service publications, including two recent ones, provide excellent guidelines for modifying silvicultural practices to maintain or improve wildlife habitat.

A publication that emphasizes the relationship between timber management and wildlife and wildlife habitat is the Southern Region's Wildlife Management Handbook (USDA Forest Service 1971), which contains much information that is applicable to other Regions. Another publication that emphasizes this relationship is Wildlife Habitats in Managed Forests--the Blue Mountains of Oregon and Washington (USDA Forest Service 1979). Indeed, this publication provided for the first time a comprehensive framework by which the habitat needs of wildlife could be integrated readily into plans for intensive forest management. Yet another useful publication is Managing Forest Lands for Wildlife (Colorado Division of Wildlife 1984). Developed for the Rocky Mountain Region, this book covers many principles and practices applicable to a much wider area. In fact, this publication represents the state of the art in terms of improving wildlife habitat through silvicultural practices.

The latest in this series of related publications are Management of Wildlife and Fish Habitats in Forests of Oregon and Washington (USDA Forest Service 1985) and Wildlife Habitat in Managed Rangelands--the Great Basin of Southeastern Oregon (USDA Forest Service and U.S. Bureau of Land Management 1986; Chris Maser and Jack Ward Thomas, technical editors). The first does for western Oregon and Washington what Jack Ward Thomas' pioneering effort (USDA Forest Service 1979) did for the Blue Mountains of eastern Oregon. Besides describing the relationships between timber management and wildlife and wildlife habitat, the chapter on "Silvicultural Options" in Management of Wildlife and Fish Habitats covers the application of silvicultural concepts and principles to wildlife habitat enhancement. The second publication mentioned above, Wildlife Habitat in Managed Rangelands, follows a similar approach, providing principles for resource coordination and guidelines for vegetation manipulation to achieve wildlife goals on managed rangelands. Of special interest is chapter 14, "Management Practices and Options," which deals primarily with livestock in relation to wildlife and wildlife habitat.

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Appendix A
Common and Scientific Names of Animals Mentioned in Chapter 3

COMMON NAME	SCIENTIFIC NAME
American coot	Fulica americana
Beaver	Castor canadensis
Blue-winged teal	Anas discors
Bufflehead	Bucephala albeola
Canada goose	Branta canadensis
Canvasback	Aythya valisineria
Common snipe	Capella gallinago
Deer	Odocoileus spp.
Double-crested cormorant	Phalacrocorax auritus
Gadwall	Anas strepera
Great blue heron	Ardea herodias
Green-winged teal	Anas carolinensis
Hooded merganser	Lophodytes cucullatus
Kestrel	Falco sparverius
Lesser yellowlegs	Totanus flavipes
Little blue heron	Florida caerulea
Mallard	Anas platyrhynchos
Muskrat	Ondatra zibethica
Otter	Lutra canadensis
Pectoral sandpiper	Erolia melanotos
Pintail	Anas acuta
Rabbit	Sylvilagus spp.
Raccoon	Procyon lotor
Redhead	Aythya americana
Shoveler	Spatula clypeata
Sora	Porzana carolina
Starling	Sturnus vulgaris
Yellow-crowned night heron	Nyctanassa violacea
Wood duck	Aix sponsa

Appendix B
Common and Scientific Names of Plants Mentioned in Chapter 3

COMMON NAME	SCIENTIFIC NAME
Ash	Fraxinus spp.
Aster	Aster spp.
Arrowgrass	Triglochin maritima
Arrowhead	Sagittaria latifolia
Banana waterlily	Nymphaea mexicana (Castalia flava)
Beech	Fagus grandifolia
Big duckweed	Spirodela polyrhiza
Birch	Betula spp.
Black gum	Nyssa sylvatica
Black locust	Robinia pseudo-acacia
Black spruce	Picea mariana
Bladderwort	Utricularia spp.
Boxelder	Acer negundo
Bulrushes	
- Alkali	Scirpus paludosus
- Common threesquare	S. americanus
- Dwarf	S. debilis
- Hardstem	S. acutus
- Olney's threesquare	S. olneyi
- Saltmarsh	S. robustus
- Softstem	S. validus
- Southern	S. californicus
- Swamp	S. etuberculatus
Bur marigold	Megalodonta beckii
Burreed	Sparganium americanum
Buttonbush	Cephalanthus occidentalis
Cattail	Typha spp.
Chufa	Cyperus esculentus
Cherrybark oak	Quercus falcata
Coontail	Ceratophyllum demersum
Cordgrass	Spantina spp.
Creeping waterprimrose	Jussiaea diffusa
Cut-grass	Leersia oryzoides
Cypress	Chamaecyparis thyoides
Duckpotato	Sagittaria heterophylla, S. cuneata and S. latifolia
- Delta	Sagittaria platyphylla
Duckweed	Lemna spp.
Eelgrass	Zostera marina
Elm	Ulmus spp.

COMMON NAME	SCIENTIFIC NAME
Glasswort	Salicornia spp.
Hackberry	Celtis occidentalis
Hickory	Carya spp.
Honey locust	Gleditsia triacanthos
Japanese millet	Echinochloa frumentacea
Jungle-rice	Echinochloa colonum (South)
Ladysthumb	Polygonum persicaria
Leatherleaf	Chamaedaphne calyculata
Loblolly pine	Pinus taeda
Mana grass	Glyceria borealis
Manateegrass	Cymodocea manatorum
Marsh cinquefoil	Pontentilla palustris
Meadowsweet	Spiraea latifolia
Mermaidweed	Proserpinaca palustris
Milfoil	Myriophyllum spp.
Muskgrass	Chara spp.
Naiad	Najas flexilis
Needlerush	Juncus roemerianus
Nuttall oak	Quercus nuttallii
Oak	Quercus spp.
Overcup oak	Quercus lyrata
Pickerelweed	Pontederia cordata
Pin oak	Quercus palustris
Pine	Pinus spp.
Pondweeds	
- Bushy	Najas flexilis
- Claspingleaf	Potamogeton perfoliatus
- Dotted	Potamogeton pulcher
- Flat-stemmed	Potamogeton zosteriformes
- Floatingleaf	Potamogenton natans
- Grass-leaved	P. pusillus, P. foliosus and others
- Horned	Zannichellia palustris
- Large leaf	Potamogeton amplifolius
- Leafy	Potamogeton diversifolius
- Longleaf	Potamogeton americanus
- Ribbonleaf	Potamogeton epihydrus
- Richardson's	Potamogeton richardsonnii
- Robbins	Potamogeton robbinsil
- Sago	Potamogeton pectinatus
- Variableleaf	Potamogeton gramineus
Purple loosestrife	Lythrum salicaria
Rice cutgrass	Leersia oryzoides
Reed canarygrass	Phalaris arundinacea
Saltmarsh cordgrass	Spartina alterniflora
Sand-bar willow	Salix interior
Sedge	Carex spp.
Shoalgrass	Halodule wrightii
Small duckweed	Lemna minor

COMMON NAME	SCIENTIFIC NAME
Smartweeds	
- Dotted	_Polygonum punctatum_
- Largeseed	_P. pennsylvanicum_
- Marsh	_P. muhlenbergii_
- Nodding	_P. lapathifolium_
- Southern	_P. portoricense_
- Swamp	_P. hydropiperoides_
- Water	_P. amphibium_
- Waterpepper	_P. hydropiper_
Soft Maple	_Acer rubrum_
Southern naiad	_Najas guadalupensis_
Sphagnum	_Sphagnum_ spp.
Spatterdock	_Nuphar_ spp. (Nymphaea)
Spikerushes	
- Dwarf	_Eleocharis parvula_
- Gulf-coast	_E. cellulosa_
- Jointed	_E. equisetoides_
- Squarestem	_E. quadrangulata_
Sticktight	_Bidens_ spp.
Stiff wapato	_Sagittaria heterophylla_
Surfgrass	_Phyllospadix_ spp.
Swamp chestnut oak	_Quercus michauxii_
Swamp milkweed	_Asclepias incarnata_
Swamp white oak	_Quercus bicolor_
Sweet flag	_Acorus calamus_
Sweetgum	_Liquidambar styraciflua_
Sycamore	_Platanus occidentalis_
Tide marsh waterhemp	_Acnida cannabina_
Tupelo	_Nyssa aquatica_
Watercress	_Nasturtium officinale_
Waterhyssop	_Bacopa monnieria_
Waterlily	_Nymphaea odorata_ (East), _N. tuberosa_ (Middle West)
Waterpepper	_Polygonum hydropiper_
Waterweed	_Anacharis canadensis_
Water crowfoot	_Ranuneulus tricophyllus_
Water locust	_Gleditsia aquatica_
Water oak	_Quercus nigra_
Water parsnip	_Sium suave_
Water shield	_Brasenia chreberi_
Wildcelery	_Vallisneria spiralis_
Wildrice	_Zizania aquatica_
Wild millets	_Echinochloa crusgalli_, _E. walteri_, _E. colonum_ (South)
Willow	_Salix_ spp.
Widgeongrass	_Ruppia maritima_
White water lily	_Nymphaea_ spp.
Yellow clover	_Melilotus officinalis_
Yellow poplar	_Liriodendron tulipifera_
Yellow water lily	_Nymphaea_ spp.

Appendix C
Common and Scientific Names of Mammals Mentioned in Chapter 4

COMMON NAME	SCIENTIFIC NAME
Bighorn sheep	*Ovis canadensis*
Columbian ground squirrel	*Citellus columbianus*
Cottontail	*Sylvilagus floridanus*
Deermouse	*Peromyscus maniculatus*
Elk	*Cervus elaphus*
Flying squirrel	*Glaucomys* spp.
Fox, red and gray	*Vulpes vulpes* and *Urocyron cinereoargenteus*
Gray squirrel	*Sciurus carolinensis*
Hoary bat	*Lasiurus cinereus*
Least weasel	*Mustela rixosa*
Moose	*Alces alces*
Mule deer	*Odocoileus hemionus*
Muskrat	*Ondatra zibethicus*
Northern flying squirrel	*Glaucomys sabrinus*
Opossum	*Didelphis masupialis*
Pika	*Ochotona princeps*
Porcupine	*Erethizon dorsatum*
Pronghorn antelope	*Antilocarpa americana*
Raccoon	*Procyon lotor*
Red squirrel	*Tamiasciurus hudsonicus*
River otter	*Lutra canadensis*
Skunk, striped	*Mephitis mephitis*
Weasel	*Mustela* spp.
Western jumping mouse	*Zapus princeps*
White-tailed deer	*Odocoileus virginianus*
Woodchuck	*Marmota monax*

Appendix D
Common and Scientific Names of Birds Mentioned in Chapter 4

COMMON NAME	SCIENTIFIC NAME
American goldfinch	Carduelis tristis
American robin	Turdus migratorius
Bald eagle	Haliaeetus leucocephalus
Bank swallow	Riparia riparia
Barn owl	Tyto alba
Barn swallow	Hirundo rustica
Bewick's wren	Thryomanes bewickii
Black-backed three-toed woodpecker	Picoides arcticus
Blue grouse	Dendragapus obscurus
Bluebird	Sialia sialis
Bobwhite quail	Colinus virginianus
Burrowing owl	Athene cunicularia
California quail	Lophortyx californicus
Carolina wren	Thryothorus ludovicianus
Cedar waxwing	Bombycilla cedrorum
Chickadee	Parus atricapillus
Chipping sparrow	Spizella passerina
Chukar partridge	Alectoris chukar
Common flicker	Colaptes auratus
Common nighthawk	Chordeiles miror
Common raven	Corvus corax
Crested flycatcher	Myiarchus crinitus
Dark-eyed junco	Junco hyemalis
Downy woodpecker	Picoides pubescens
Dusky flycatcher	Empidonax oberholseri
Evening grosbeak	Hesperiphona vespartina
Ferruginous hawk	Buteo regalis
Flicker	Colaptes spp.
Gambel's quail	Lophortyx gambelii
Golden eagle	Aquila chrysaetos
Golden-crowned kinglet	Regulus satrapa
Golden-fronted woodpecker	Centurus aurifrons
Goshawk	Accipiter gentilis
Great blue heron	Ardea herodias
Great horned owl	Bubo virginianus
Hairy woodpecker	Picoides villosus
House finch	Carpodacus mexicanus
House wren	Troglodytes aedon
Hungarian (gray) partridge	Perdix perdix
Ivory-billed woodpecker	Campephilus principalis
Kentucky warbler	Oporornis formosus

COMMON NAME	SCIENTIFIC NAME
Kestrel	_Falco sparverius_
Killdeer	_Charadrius vociferus_
Lincoln's sparrow	_Melospiza lincolnii_
Mourning dove	_Zenaida macroura_
Northern oriole	_Icterus galbula_
Northern three-toed woodpecker	_Picoides tridactylos_
Nuthatch	_Sitta_ spp.
Osprey	_Pandion haliaetus_
Ovenbird	_Seiurus aurocapillus_
Pheasant	_Phasianus colchicus_
Phoebe	_Sayornis phoebe_
Pileated woodpecker	_Dryocopus pileatus_
Prairie chicken	_Tympanuchus cupido_
Prairie falcon	_Falco mexicanus_
Prothonotary warbler	_Prothonotaria citrea_
Purple martin	_Progne subis_
Red-bellied woodpecker	_Melanerpes carolinus_
Red-breasted nuthatch	_Sitta canadensis_
Red-cockaded woodpecker	_Picoides borealis_
Red-headed woodpecker	_Melanerpes erythrocephalus_
Red-tailed hawk	_Buteo jamaicensis_
Robin	_Turdus migratorius_
Ruffed grouse	_Bonasa umbellus_
Sage grouse	_Centrocercus urophasianus_
Saw-whet owl	_Aegolius acadicus_
Screech owl	_Otus asio_
Sharptail grouse	_Pidiocetes phasianellus_
Sparrow hawk	_Falco sparverius_
Spotted owl	_Strix occidentalis_
Starling	_Sturnus vulgaris_
Swainson's thrush	_Catharus ustulatus_
Titmouse	_Parus bicolor_
Tree swallow	_Iridoprocne bicolor_
Turkey	_Meleagris gallopavo_
Violet-green swallow	_Tachycineta thalassina_
Wood duck	_Aix sponsa_
Woodcock	_Philohela minor_
Yellow-bellied sapsucker	_Sphyrapicus varius_
Yellow-breasted chat	_Icteria virens_
Yellow-rumped warbler	_Dendroica coronata_

Appendix E
Common and Scientific Names of Reptiles and Amphibians Mentioned in Chapter 4

COMMON NAME	SCIENTIFIC NAME
Reptiles	
Common garter snake	*Thamnophis sirtalis*
Rubber boa	*Charina bottae*
Side-blotched lizard	*Uta stansburiana*
Western fence lizard	*Sceloporus occidentalis*
Amphibians	
Bullfrog	*Rana catesbeiana*
Long-toed salamander	*Eurycea longicauda*
Pacific treefrog	*Hyla regilla*
Western toad	*Bufo boreas*

Appendix F
Common and Scientific Names of Trees Mentioned in Chapter 4

COMMON NAME	SCIENTIFIC NAME
Alpine fir	Abies lasiocarpa
Aspen	Populus spp.
Bald cypress	Taxodium distichum
Balsam fir	Abies balsamea
Basswood	Tilia americana
Black cherry	Prunus serotina
Black oak	Quercus velutina
Black spruce	Picea mariana
Blackjack oak	Quercus marilandica
Blue ash	Fraxinus quadrangulata
Box elder	Acer negundo
Butternut	Juglans cinerea
Chestnut oak	Quercus prinus
Douglas-fir	Pseudotsuga menziesii
Eastern hemlock	Tsuga canadensis
Elm	Ulmus spp.
Gambel oak	Quercus gambelii
Grand fir	Abies grandis
Green ash	Fraxinus pennsylvanica
Honey locust	Gleditsia triacanthos
Live oak	Quercus virginiana
Lodgepole pine	Pinus contorta
Northern red oak	Quercus rubra
Oak	Quercus spp.
Pine	Pinus spp.
Pinyon	Pinus edulis
Ponderosa pine	Pinus ponderosa
Post oak	Quercus stellata
Quaking aspen	Populus tremuloides
Red maple	Acer rubrum
Red pine	Pinus resinosa
Redwood	Sequoia sempervirens
Sandjack oak	Quercus cinecea
Sandshinnery oak	Quercus harvardii
Scarlet oak	Quercus coccinea
Shortleaf pine	Pinus echinata
Southern red oak	Quercus falcata
Walnut	Juglans spp.
Water oak	Quercus nigra
Western larch	Larix occidentalis
White birch	Betula papyrifera

COMMON NAME	SCIENTIFIC NAME
White cedar	*Thuja occidentalis*
White oak	*Quercus alba*
White pine	*Pinus strobus*

Appendix G
Common and Scientific Names of Shrubs Mentioned in Chapter 4

COMMON NAME	SCIENTIFIC NAME
Big sagebrush	Artemisia tridentata
Bitterbush	Purshia tridentata
Bittercherry	Prunus emarginata
Black sagebrush	Artemisia nova
Blackberry	Rubus spp.
Bluebeech (Ironwood)	Carpinusi caroliniana
Broom snakeweed	Guteirrezia sarothrae
Buckbrush	Ceanothus spp.
Buckthorn	Rhamnus spp.
Chinkapin (Chinquapin)	Castanopsis spp.
Choke cherry	Prunus pennsylvanicas
Cliffrose	Cowania mexicana
Common elderberry	Sambucus canadensis
Common snowberry	Symphoricarpos spp.
Common witch hazel	Hamamelis virginiana
Curl leaf mountain mahogany	Cercocarpus ledifolius
Currant	Ribes spp.
Dogwood	Cornus spp.
Dwarf huckleberry	Gaylossacia dumosa
Dwarf sumac	Rhus copallina
Early low blueberry	Vaccinium vacillans
Fragrant sumac	Rhus aromatica
Gooseberry	Ribes spp.
Grape vine	Vitis spp.
Gray dogwood	Cornus racemosa
Greaseweed	Sarcobatus vermiculatus
Greenbriar	Smilax spp.
Green rabbitbrush	Chrysothamnus viscidiflorus
Hawthorne	Crataegos spp.
Hazlenut	Corylus spp.
Huckleberry	Gaylussacia spp.
Hydrangea	Hydrangea spp.
Juniper	Juniperus spp.
Lespedeza	Lespedeza bicolor
Low sagebrush	Artemisia arbuscula
Mountain snowberry	Symphoricarpos oreophilus
Mulberry	Morus spp.
Northern honeysuckle	Diervilla lonicera
Nannyberry	Viburnum lentago
New Jersey tea	Ceanothus americanas
Ninebark	Physocarpus opulifolius

COMMON NAME	SCIENTIFIC NAME
Oceanspray	*Holodiscus discolor*
Persimmon	*Diospyros virginiana*
Plum	*Prunus* spp.
Redbud	*Cercis canadensis*
Red cedar	*Juniperus virginiana*
Rose	*Rosa* spp.
Rubber rabbitbrush	*Chrysothamnus nauseosus*
Russian olive	*Elaeagnus angustifolia*
Sagebrush	*Artemisia* spp.
Sand cherry	*Prunus depressa*
Serviceberry	*Amalanchier* spp.
Sheeplaurel	*Kalmia angustifolia*
Silver sagebrush	*Artemisia cana*
Smooth sumac	*Rhus glabra*
Snowbrush	*Ceanothus fendleri*
Speckled alder	*Alnus rugosa*
Spineless horseradish	*Armoracia armoracia*
Spiraea	*Spiraea* spp.
Staghorn sumac	*Rhus typhina*
Sugarberry	*Celtis* spp.
Tag alder	*Alnus rugosa*
Three tip sagebrush	*Artemisia tripartita*
True mountain mahogany	*Taxus brevifolia*
Viburnum	*Viburnum* spp.
Willow	*Salix* spp.

Appendix H
Common and Scientific Names of Forbs Mentioned in Chapter 4

COMMON NAME	SCIENTIFIC NAME
Alfalfa	*Medicago sativa*
Arrowleaf balsam root	*Balsamorrhiza sagittata*
Arrowhead	*Sagittaria* spp.
Astragalus	*Astragalus canadensis*
Cattail	*Typha* spp.
Common comandra	*Comandra umbellata*
Common sunflower	*Helianthus annus*
Coyote tobacco	*Nicotiana attenuata*
Douglas knotweed	*Polygonum douglasii*
Flaxleaf plainsmustard	*Sisymbrium linifolium*
Flaxweed tanseymustard	*Descurainia sophia*
Foothill deathcamus	*Toxicoscordium gramineum*
Gayophytum	*Gayophytum diffusum*
Goldenrod	*Solidago* spp.
Goosefoot	*Chenopodium* spp.
Hairy fleabane	*Erigeron concinnus*
Hoary phlox	*Phlox canescebs*
Lambstongue groundsel	*Senecio integerrimus*
Littleleaf pussytoes	*Antennaria microphylla*
Longleaf phlox	*Phlox longifolia*
Low pussytoes	*Antennaria dimorpha*
Mat eriogonum	*Eriogonum caespitosum*
Matroot penstemon	*Penstemon radicosus*
Monroe globemallow	*Sphaeralcea munroana*
Orange arnica	*Arnica fulgens*
Pale alyssum	*Alyssum alyssoides*
Pinnate tanseymustard	*Descurainia pinnata*
Plumeweed	*Cordylanthus ramosus*
Pondweed	*Potamogeton* spp.
Prickley pear	*Opuntia* spp.
Purpledaisy fleabare	*Erigeron corymbosus*
Red globemallow	*Sphaeralcea coccinea*
Russian thistle	*Salosola kali*
Smartweed	*Polygonum* spp.
Sticky geranium	*Geranium viscosissimum*
Tailcup lupine	*Lupinus caudatus*
Tapertip hawksbeard	*Crepis acuminata*
Tongueleaf violet	*Viola nuttallii*
Tumble mustard	*Norta altissima*
Uinta sandwort	*Aranaria utahensis*
Velvet lupine	*Lupinus leucophyllus*

COMMON NAME	SCIENTIFIC NAME
Wavyleaf thistle	Cirsium undulatum
Western yarrow	Achillea millefolium
Whitlow-wart	Paronychia spp.
Wild lettuce	Lactuca canadensis
Wild onion	Allium stellatum
Wyeth eriogonum	Eriogonum heracleoides

Appendix I
Common and Scientific Names of Grasses and Grasslike Plants Mentioned in Chapter 4

COMMON NAME	SCIENTIFIC NAME
Grasses	
Big bluegrass	*Poa ampla*
Bluebunch wheatgrass	*Agropyron spicatum*
Bottlebrush squirreltail	*Sitanion hystrix*
Brome grass	*Bromus* spp.
Canary grass	*Phalaris* spp.
Cheat grass (cheat)	*Bromus tectorum*
Columbia needle grass	*Stipa columbiana*
Crested wheatgrass	*Agropyron cristatum*
Cusick bluegrass	*Poa cusickii*
Idaho fescue	*Festuca idahoensis*
Indian ricegrass	*Oryzopsis hymenoides*
Intermediate wheatgrass	*Agropyron intermedium*
June grass	*Koeleria cristata*
Kentucky bluegrass	*Poa pratensis*
Little bluestem	*Schizachyrium scoparium*
Mutton grass	*Poa fendleriana*
Needle-and-thread	*Stipa comata*
Nevada bluegrass	*Poa nevadensis*
Sandberg bluegrass	*Poa secunda*
Switch grass	*Panicum* spp.
Tall wheat grass	*Agropyron elongatum*
Thickspike wheat grass	*Agropyron dasystachyum*
Thurber needlegrass	*Stipa thurberiana*
Timothy	*Phleum pratense*
Western needlegrass	*Stipa occidentalis*
Western wheatgrass	*Agropyron smithii*
Grass-like plants	
Bulrush	*Scirpus* spp.
Douglas sedge	*Carex douglasii*
Thread leaf sedge	*Carex filifolia*

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